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WSEG REPORT 197

DESIGN OF A FIELD TEST FOR PROBABILITY OF HIT BY ANTIAIRCRAFT GUNS

February 1973

Including

IDA PAPER P-921

J. R. Transue, *Project Leader*

IDA

INSTITUTE FOR DEFENSE ANALYSES
SYSTEMS EVALUATION DIVISION

WSEG

WEAPONS SYSTEMS EVALUATION GROUP
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13 FEB 1973

MEMORANDUM FOR DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

SUBJECT: Design of a Field Test for Probability of Hit by Antiaircraft Guns

1. The study contained in this report, WSEG 197, is responsive to that portion of the Memorandum for WSEG from the Director of Defense Research and Engineering dated 12 May 1972, dealing with the Probabilities of Hit of Aircraft in Close Air Support Operations.

2. The test design presented in this report provides the basis for a detailed test plan to be developed by the Test Director. The design describes what data and major instrumentation will be required, the test conditions, aircraft support, antiaircraft gun systems and range requirements for the field test. In addition, the report describes a preliminary plan for analysis and evaluation. The field test described is one element in a program to validate and improve mathematical models of an antiaircraft gun firing at an aircraft.

Glenn A. Kent
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Lieutenant General, USAF
Director

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(14) PAPER P-921

(6) # DESIGN OF A FIELD TEST FOR PROBABILITY OF HIT BY ANTIAIRCRAFT GUNS,

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PREFACE

In 1972 WSEG/IDA conducted a study of the feasibility of a test and evaluation program for probability of hit of anti-aircraft guns firing on aircraft. The study report, WSEG Report 190, outlined an approach for such a program and listed three preliminary tests that are needed to confirm the feasibility of the instrumentation and test approach. The three preliminary tests were described more fully in WSEG Report 191. The present report constitutes the design of the field test. It is intended to serve as the basis for detailed test planning by the Joint Service Test Director.

This test design has been prepared by a WSEG/IDA team that includes Dr. G. L. Brown; Col. R. G. Dingman, USAF (WSEG Project Officer); Dr. C. T. Ireland; Capt. D. F. X. McPadden, USN; Dr. J. A. Ross; Col. C. R. Sykes, USA; Mr. C. M. Tiffin; and Dr. J. R. Transue (Project Leader). The contributions of the technical reviewers--Dr. J. Bracken, Mr. J. W. Graves, Dr. R. R. Kneece, Mr. A. O. Kresse, and Dr. S. A. Musa--and of the editor, Mr. L. C. Eggert, are gratefully acknowledged.

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INTRODUCTION AND SUMMARY

The objective of this report is to present the design of a joint-Service field test of antiaircraft guns firing at aircraft. The field test is one element in a program to validate and improve mathematical models of an antiaircraft gun firing at an aircraft. The test design is intended to serve as the basis for a detailed test plan to be developed by the Joint Service Test Director. The design includes a description of:

- Test conditions--controlled variables and their values; sequence of trials.
- Data requirements--data elements for each gun type; accuracy of data; frequency of measurement; data processing.
- Major instrumentation--instrumentation for tracking the aircraft and measuring the tilt of the gun mount.
- Aircraft and antiaircraft gun systems--number and type of aircraft; sortie requirements; gun, guncrew, and ammunition requirements.
- Range requirements--space; facilities; safety.
- Preliminary plan for analysis and evaluation--methods to be used.

The field test consists of the firing of four antiaircraft guns at fixed- and rotary-wing aircraft. Breakup ammunition will be used so that the aircraft are not endangered. Aircraft positions and gun pointing directions will be measured, and the probability of hit will be calculated from these measurements and from ballistics data.

A. BACKGROUND

During the last 5 years, the Army, Navy, and Air Force and the Department of Defense have all made use of studies and analyses in which the expected destruction of aircraft by antiaircraft guns was evaluated by means of mathematical models. The purposes of these studies have ranged from the development of tactics to the design of armament and from the determination of force structure to the comparison of aircraft types. Mathematical models have been used to evaluate such broad issues as whether guns or missiles should be used to provide forward area air defense and whether fixed- or rotary-wing aircraft are more suitable for defending against an attack by an armor force. Mathematical models are used in these studies for several reasons:

- Data from actual combat are not available.
- The cost of conducting the numerous field test trials that would be needed to establish the loss rates of aircraft to antiaircraft guns under many sets of conditions is prohibitive.
- It is not possible to test systems during concept development and early stages of system optimization because the systems do not exist.
- Foreign systems are not always available to test.

In these frequently occurring situations, mathematical models provide a readily available and relatively inexpensive way to obtain estimates of aircraft losses to antiaircraft guns.

Because these mathematical models play an influential role in net technical assessment and in decisions relating to operational doctrine, tactics, force structure, procurement of weapons, and the direction of research and development, they assume a great importance. If the models produce valid estimates of aircraft losses to antiaircraft guns, the use of the models can contribute greatly to better decisions. But if the models produce invalid estimates, their use may lead to grievous mistakes.

Several different models are in almost daily use, computing estimated aircraft losses. Yet, it is known that, in spite of the obvious importance of accuracy and objectivity, the models do not agree with one another. When five of the more prominent models were used to simulate a variety of engagements of aircraft by antiaircraft guns, the results varied widely from model to model.[1] Furthermore, combat data have not been sufficiently complete to determine which of the models, if any, produce valid estimates.

In view of this situation, DDR&E asked WSEG/IDA to study the feasibility of measuring probability of hit in a field test and evaluation program.[2] The study considered antiaircraft guns firing at U.S. fixed- and rotary-wing aircraft providing close air support in Europe in the mid-1970s.[3] It concluded that the instrumentation for such a test could be provided, and it stated that:

> The objective of a test and evaluation program for probability of hit should be to establish the validity (or limits on the validity) of mathematical models used to determine the probability of hit of fixed- and rotary-wing aircraft being fired on by antiaircraft guns when the conditions of engagement are known. The validation of models should establish the accuracy with which their submodels (of tracking, estimation of fire control inputs, determination of aimpoint, computation of mean point of impact, and computation of probability of hit) agree with empirical data from testing.

In addition, the study stated that "The program. . .should provide a methodology and an empirical data base that can be used

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[1]Memorandum, J. Ross to JAAP Model Comparison Working Group, "Minutes of Joint Model Comparison Group Meeting at IDA 9 January 1973," dated 15 January 1973.

[2]The physical vulnerability of aircraft (i.e., the probability that an aircraft is lost given that it is hit by a particular type of projectile) is being investigated by the Services and by the Joint Technical Coordinating Groups for Munitions Effectiveness (JTCG/ME) and for Aircraft Survivability (JTCG/AS).

[3]Feasibility of a Test of Probability of Hit by Antiaircraft Guns, WSEG Report 190, August 1972.

both to validate and to guide development and improvement of models." The program consists of three elements:

- An analysis and comparison of the models of interest on the basis of theory and currently available data. This is being performed by WSEG/IDA with the cooperation of the JTCG/ME.
- A test program encompassing preliminary tests,[1] the field test described in this report, and (possibly) related laboratory tests of gun systems.
- Validation and improvement of the models through an analysis of the test data in relation to similar "data" produced by the models.[2] This is to be performed by WSEG/IDA.

The following field test approach was specified in the WSEG/IDA study:[3]

- Use combat aircraft as aerial targets, and have these aircraft perform specified maneuvers appropriate for delivery of ordnance in close air support operations. No air-to-surface ordnance will be expended.
- Have Soviet antiaircraft guns (or guns that simulate Soviet weapons) deliver realistic simulated fire at the aircraft, making use of "breakup" ammunition (i.e., ammunition with projectiles that break up into metallic powder upon emerging from the gun barrel). Such ammunition will reproduce the normal gun functioning and the recoil, flash, smoke, and dust of ordinary combat ammunition without endangering the aircraft. The guns will be fired by U.S. Army air defense crews.
- Measure aircraft position and gun pointing direction, and use ballistics data to determine probability of hit.

DDR&E subsequently decided to proceed with the field test. Both the Army and the Air Force are to participate. The Army has been designated executive agent and has selected Col. Thomas

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[1] Design of Preliminary Tests, Probability of Hit by Antiaircraft Guns, WSEG Report 191, August 1972.

[2] In this study, *validation* of a model means determination of the differences between data computed with the model and comparable data that would result from many actual occurrences of the phenomena being modeled.

[3] WSEG Report 190, op. cit.

Ostrom as the Joint Service Test Director. The overall program is now referred to as HITVAL, a name originally applied to the WSEG/IDA study.

B. SCOPE

The scope of the field test is confined to the period during which the aircraft is observed (visually or with radar) by the antiaircraft gun system. The probability of acquiring the aircraft as a target is not included in the test, but reaction time of the antiaircraft gun system is included. The broader issues such as the frequencies with which various conditions of engagement (visibility, lighting, numbers of guns, early warning, gun status, etc.) are likely to occur are not a part of the field test. These subjects should be considered in subsequent studies, and perhaps they should be investigated by subsequent field tests. The physical vulnerability of the aircraft (i.e., the effect of being hit) and the effects of ECM or other countermeasures on the performance of the antiaircraft guns are not included.[1] Both optical and radar-directed antiaircraft guns are used; both fixed- and rotary-wing aircraft are used. Some trials involve one fixed-wing aircraft, while others involve four; some trials involve one rotary-wing aircraft, while others involve two. Aircraft fly both straight and maneuvering flight paths.

C. SUMMARY

The essential features of the test design are summarized below. The ensuing chapters provide additional detail.

1. Test Conditions

The experimental design is a combination of several designs that involve the following factors:

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[1]Another WSEG/IDA study considers a test and evaluation program for electronic warfare.

- For fixed-wing aircraft: dive angle, speed, breakaway distance, breakaway acceleration, exit maneuver, "target" offset, number of aircraft, firing and nonfiring, crew, and crew fatigue.
- For rotary-wing aircraft: tactics, offset distance, firing and nonfiring, crew, and crew fatigue.

The design consists of 256 trials in which breakup ammunition is fired and 128 trials with no firing. There are 176 trials with one fixed-wing aircraft and 48 trials with four fixed-wing aircraft. There are 40 trials with one rotary-wing aircraft and 120 trials with two rotary-wing aircraft.

2. Data Requirements and Major Instrumentation

For every trial, the following elements should be measured throughout the encounter:[1]

- Aircraft position.
- Gun pointing angles.
- Angles of the sight or tracking radar; alternatively, the angular tracking error (i.e., angles giving the direction of the tracking device relative to the line of sight).
- Inputs to the fire control computer, which vary with gun type and firing mode, as described in Chapter III.

For every trial and gun, the initial gun angles and fire control system settings should be recorded, as should be the time that the target is detected (either visually or by radar), the time that firing could begin, and the time that each round is fired; the nature of any malfunctions of equipment, any condition or activity of the guncrew, and any other condition that could invalidate the trial should also be recorded.

For every trial with rotary-wing aircraft, the times of unmask and remask should be determined for each gun throughout the period from the first time that the gun could fire to the last time that the gun could fire.

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[1]This and other lists in the Summary are not exhaustive.

The major instrumentation should be a laser tracker, four AN/FPS-16 radars or equivalent, event recorders, and a communications network with separate nets for air traffic control, guncrews, and test personnel.

3. Aircraft and Antiaircraft Gun Systems

The following resources should be provided for the conduct of the test.

a. Aircraft Sorties

Aircraft are expected to fly three or four trials per sortie, resulting in:[1]

- 92 sorties by F-4 aircraft.
- 32 sorties by AX or A-37 aircraft.
- 48 sorties by AH-1 COBRA aircraft.
- 48 sorties by LOH (light observation helicopter) aircraft.

b. Guns

- One ZU-23 twin 23mm, Soviet.
- One S-60 single 57mm with optical-mechanical fire control system, Soviet.
- One S-60 with PUAZO 6-60 fire director, D-49 sight and rangefinder, and SON-9 radar, Soviet.
- One 5PFZ-B twin 35mm, Federal Republic of Germany.

The Soviet weapons are types that are still in the Soviet operational inventory. In addition, the S-60 provides a basis for evaluation of the Soviet ZSU-57-2, a self-propelled twin 57mm antiaircraft gun. The FRG twin 35mm antiaircraft tank 5PFZ-B is included because it is an application of present-day technology to a self-propelled antiaircraft gun system.

[1]Does not include any allowance for the repetition of invalid trials.

c. Guncrews

There will be four crews for each gun plus spare crew members, as explained in Chapter IV. These crews should be obtained from Army air defense units. About 8 to 12 weeks are required for training the guncrews. This need not be accomplished at the test site. Training of crews for the 5PFZ-B should be performed by FRG or contractor personnel in Europe.

d. Ammunition

- 15,000 breakup rounds and 2,000 lethal rounds (for training) for the ZU-23.
- 10,000 breakup rounds and 2,000 lethal rounds for the S-60.
- 10,000 breakup rounds for the 5PFZ-B.

4. Range Support

The test will require airspace from ground level to 7 km AGL (above ground level) within a circle of 15-km radius. Terrain must be gently rolling with enough relief or vegetation to permit rotary-wing aircraft to rise from concealed locations. The guns should be located within a circle of 250-meter radius. Easily distinguishable markings should be placed at positions 1.5 km from the center of the gun circle to serve as "targets" for the aircraft. (Aircraft do not expend ordnance.) The test will require the range for about 8 weeks. An additional 2 weeks will be required for post-test operations.

5. Data Analysis and Evaluation Plan[1]

This subsection summarizes the preliminary plan for analysis. The plan and methods will be developed further before the test.

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[1]To be executed by IDA/WSEG.

For each gun, the probability of hit will be computed (1) for each round fired, (2) for all rounds fired, (3) for individual hypothetical rounds fired at constant intervals of time while the aircraft is within range, and (4) for all such hypothetical rounds. These computations will be performed for each trial using ballistics data derived or verified in the Ballistics Verification Test, one of the preliminary tests.[1]

The determination of probability of hit will require computation of the mean miss vector. This is defined as the vector from a reference point on the aircraft (typically a nominal center of gravity) to a projectile on the mean trajectory when the aircraft and projectile are equidistant from the gun. The mean trajectory is a line that would be approached by the average of a large number of projectiles if they were all fired with the same aimpoint. Denoting the components of the mean miss vector (in a plane perpendicular to the line of sight) as DX and DY, the following measures of merit will also be computed:

$$A = \left\{\frac{1}{N}\sum_{i=1}^{N} DX_i^2\right\}^{1/2} \qquad B = \left\{\frac{1}{N}\sum_{i=1}^{N} DY_i^2\right\}^{1/2} \qquad C = \left\{A^2 + B^2\right\}^{1/2}$$

Here the index refers to a particular round and N is the total number of rounds fired by the gun on a particular trial. Similarly, the root mean squared error[2] in tracking (range, azimuth, and elevation), in estimated velocity of the aerial target, and in aimpoint (gun azimuth and elevation) will also be computed. The average value of the mean miss vector, where the average is computed over all rounds in a trial, is another useful measure of merit of a gun system. This "mean of means" will be calculated.

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[1]Existing ballistics data will be used for the 5PFZ-B.

[2]The error will be measured as the difference between the value the gun system is using (for range to the target, azimuth, or elevation) and the corresponding value derived from the instrumentation system.

The above measures will be computed for each gun and each trial without regard to the models being validated. The models will then be used to simulate the trials and to obtain the models' estimates of the variables used in computing those measures. The models' estimates will be compared with the field test data. Consider aimpoint as an example. If Θ_t and Θ_m are the azimuth angles of the gun from test data and a model, then $\Delta\Theta = \Theta_m - \Theta_t$ is the amount the model differs from the test data at the particular instant. $\Delta\Theta$ will be computed at N times during a trial, and the root mean square

$$\left\{\frac{1}{N}\sum_{i=1}^{N} \Delta\Theta_i^2\right\}^{\frac{1}{2}}$$

will be computed for each model and each trial.

The experimental design is such that it is possible to estimate the effect of each of the factors in the design and each of the two-factor interactions. This will be done on the basis of the probabilities of hit computed from field test data and on the basis of mean miss vectors. The technique planned is the usual analysis of variance. This same technique will be used to compare models to the field test data. The difference between the model result and the field test result will be computed for each trial. Analysis of variance performed on these differences will provide an estimate of the mean difference, the main effects, and the two-factor interactions. Low values of the mean difference and no significant main effects or two-factor interactions would indicate model validity throughout the spectrum of test conditions.

Chapter II

TEST CONDITIONS

This chapter presents the objectives of the experimental design and describes the factors and levels included in the design. It then presents the design in a tabular form that shows the order of testing as well as the combinations of factor levels for each trial.

The experimental design is simply a description of the test conditions of each trial of an experiment. The test conditions are described by specifying the level (value) of each factor (controlled variable). For example, in part of the present design, one of the factors is the dive angle of the fixed-wing aerial target. This factor has two levels--15 degrees and 45 degrees.

A. OBJECTIVES OF THE EXPERIMENTAL DESIGN

There are two objectives of carefully selecting the set of test conditions making up the experimental design. The first objective is to permit the use of particular methods of mathematical statistics to determine the influence of the factors on the observations (the values of observed variables). Thus, if the dive angle of aerial targets affects the angular tracking accuracy of an antiaircraft gun, a statistical test for this main effect (the effect of a single factor) would likely be significant (would indicate that there is an effect). If the experiment were conducted repeatedly, the fraction of times that the statistical test would be significant would depend on the magnitude of the effect and on the number of trials in each

experiment, the fraction being greater for larger effects and for larger numbers of trials.

The second objective is to ensure that the experiment covers the wide spectrum of conditions for which the models (the mathematical models of antiaircraft guns firing at aircraft) are intended and for which the models should be validated. For example, the breakaway distances and offsets used in the tests with fixed-wing aircraft provide a spectrum of angular tracking rates and accelerations at the gun.

B. FACTORS AND LEVELS OF THE EXPERIMENTAL DESIGN

The experimental design for the HITVAL test consists of several parts each of which is itself an experimental design. That is, there are fixed-wing and rotary-wing parts, firing and nonfiring parts, etc. The parts are so designed that particular pairs can be combined to form a larger design. This will be clarified now by considering the tabulated design.

Each of Tables 1, 2, and 3 lists the factors and levels for a part of the design. The symbols listed in these tables are used in later tables to concisely give the test conditions. In Tables 1, 2, and 3 the factor *crew* refers to the crew of an antiaircraft gun. There are four crews for each gun. The factor *crew* exists at four levels--designated by the symbols C_1, C_2, C_3, and C_4. Note that *level* does not imply skill level.

It is believed that the performance of the guncrew can make a great difference in the effectiveness of antiaircraft guns, particularly guns that rely on manual tracking or other manual functions. Unfortunately, there is presently no way to determine in advance how well individuals will perform as members of a guncrew. If only one crew were used on a particular gun, the crew might be unusually proficient or unusually inept. Including four crews for each weapon reduces the risk that an unusual crew will cause the test results to be extreme.

Table 1. FACTORS AND LEVELS--FIXED-WING SINGLE AIRCRAFT, FIRING

Factor	Level 1	Level 2	Level 3	Level 4
Crew	C_1, Crew 1	C_2, Crew 2	C_3, Crew 3	C_4, Crew 4
Fatigue	F_1, Fresh	F_2, Tired	--	--
Dive Angle	D_1, 15°	D_2, 45°	--	--
Breakaway Distance[a]	B_1, 1.5 km	B_2, 3 km	--	--
Breakaway Acceleration	A_1, 3g	A_2, 5g	--	--
Exit Maneuver	E_1, Up Helix	E_2, Down Helix	--	--
Speed	S_1, 300 knots	S_2, 450 knots	--	--
Offset	H_1, <250m	H_2, 1.5 km	--	--

NOTE: Table 4 presents the corresponding experimental design. It is a one-fourth replicate consisting of 128 trials.

[a]Slant range of the aircraft from its "target" at breakaway.

Table 2. FACTORS AND LEVELS--ROTARY-WING AIRCRAFT

Factor	Level 1	Level 2	Level 3	Level 4
Crew	C_1, Crew 1	C_2, Crew 2	C_3, Crew 3	C_4, Crew 4
Fatigue	F_1, Fresh	F_2, Tired		
Tactics	T_1, Popup Steady	T_2, Popup Jink	T_3, Moving Fire	T_4, Nap-of-Earth Fly-By
Distance	K_1, 1 km	K_2, 2 km	K_3, 3 km	--
Firing	R_1, Non-firing	R_2, Firing	--	--

NOTE: Table 5 presents the corresponding experimental design for the firing trials. Table 6 presents the nonfiring trials. The firing trials are a full replicate of 96 trials. The nonfiring trials are a full replicate of a reduced design (i.e., K_2 does not appear). There are 64 nonfiring trials.

Table 3. FACTORS AND LEVELS--FIXED-WING AIRCRAFT WITH TACTICS

Factor	Level 1	Level 2	Level 3	Level 4
Crew	C_1, Crew 1	C_2, Crew 2	C_3, Crew 3	C_4, Crew 4
Tactics	T_1, Straight and Level	T_2, Single Aircraft	T_3, Curvilinear	T_4, Wagon Wheel
Offset	H_1, <250 m	H_2, 1.5 km		
Firing	R_1, Non-Firing	R_2, Firing		

NOTE: Tables 6 and 7 give the firing and nonfiring trials of the design corresponding to these factor levels. Together the trials of Tables 6 and 7 are a full replicate of 64 trials plus a replicate of the 32 nonfiring trials.

As mentioned in Chapter IV, the crews should be so composed that all crews labeled "Crew 1" share certain characteristics, and similarly for the crews with the other labels. Then if these characteristics are highly correlated with performance, the test will likely show a significant effect for the factor *crew*. The characteristics, to be determined by human factors specialists, could be the results of psychomotor tests, visual search tests, and visual acuity tests.

The factor *fatigue* is included to determine whether guncrews perform better when rested than when fatigued. At present it is not certain that a satisfactory way of producing and controlling the amount of fatigue will be found. If none is found, fatigue will be deleted from the test, but the number of trials will not change. The experimental design presented in Tables 4, 5, 6, and 7 *(pages 20, 23, 25, and 26, respectively)* will still be used but with F_1 and F_2 deleted.

The remaining factors in Table 1 describe the flight paths of fixed-wing aircraft. These factors are presumed to affect probability of hit. The particular levels chosen for the design

are representative of tactics used in providing close air support. For example, a 45-degree dive angle and 1.5-km breakaway distance are typical of delivery of unguided bombs, while this same dive angle and 3-km breakaway distance correspond to delivery of guided bombs. A 15-degree dive angle and 1.5-km breakaway distance are representative of strafing or delivery of high-drag bombs, while this same dive angle and 3-km breakaway distance are typical of delivery of short range air-to-surface missiles.

The breakaway acceleration levels, 3 g's and 5 g's, are in the range of common practice. The exit maneuvers are both found in practice; by including both, the gunners will be faced with a less predictable target than otherwise would be the case. The lower aircraft speed, 300 knots, is typical of AX-type close air support aircraft, while the higher speed, 450 knots, corresponds to high performance fighter bombers. Minor variations in the values achieved for the factors will occur from trial to trial, and in the case of particular combinations (those that involve 45-degree dive angle, 1.5-km breakaway distance, 3-g breakaway acceleration, and 450-knot speed) minor variations may be required to avoid flying into the ground. A slight increase in breakaway acceleration will result in a safe flight path.

Use of the AX or A-37 at the lower speed and the F-4 at the higher speed will confound speed with aircraft type.[1,2] This is not considered a disadvantage because each aircraft is representative of the aircraft that would provide close air support while operating in its particular speed regime.

Offset refers to the lateral distance of the "target" of the aircraft from the gun positions. Its two values will result in different time histories of gun angular rates and accelerations.

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[1]That is, the effect of speed and the effect of aircraft type will not be directly distinguishable from each other in the test results.

[2]The Air Force has suggested that one of the prototype AX aircraft may be available for the test.

It is likely that the guncrews will sometimes not see the fixed-wing aircraft until it is too late to deliver fire. While this may be an interesting result, it provides no information about guns *firing* at aircraft. To preclude this occurring too frequently, it is suggested that the test controllers at the guns be continually informed of the range from the guns to the aircraft and that, whenever this range falls below some particular value and the crew of a gun has not detected the aircraft, the controller at that gun should point out the aircraft. As noted in Chapter III, all such instances should be identified in the trial records.

All of the trials corresponding to Table 1 involve firing of breakup ammunition, and all use a single aircraft as the target.

Table 2 lists four helicopter tactics. In the two popup maneuvers, the helicopter is initially masked. In *popup steady*, it rises above the mask, hovers for a prescribed period, and descends behind the mask. In *popup jink*, instead of hovering the helicopter moves left and right or up and down or both. The popup tactics represent two methods of delivering missiles. The popup steady tactic could also be used for firing rockets or guns.

The total period of exposure in the popup trials should vary from trial to trial so that the guncrews will not know how much time they have to deliver fire. However, all guns should fire during a trial; if they do not, it should be repeated. Until the test is started, it will not be known how quickly and consistently the guncrews detect the helicopters. In the absence of this information, the following procedure is recommended: For each trial, randomly select a minimum exposure time. The frequency data of CDCEC test 43.6[1] can be used as a guide. Inform the helicopter pilot and the controller

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[1]"Evaluation of TOW/Helicopter Systems and Antiaircraft Engagement Time," Operational Test and Evaluation of Certain Close Air Support Test Programs, WSEG Report 189 (IDA Study S-403), August 1972, CONFIDENTIAL.

at each gun of this time. Tell the controllers when unmask occurs, and count down the seconds to scheduled remask. Instruct the controllers to point out the helicopter to any guncrew that has not detected it early enough to deliver fire before scheduled remask. The time of alerting the guncrews can be adjusted during the test to ensure that the guncrews are rushed in preparing to fire and to ensure that the number of trials that must be repeated is not excessive.

The third tactic is an attack tactic known as "moving fire from forward motion." In this study it will be called simply *moving fire*. In this tactic a helicopter flies nap-of-earth directly toward its target. In the field test the "target" will be the antiaircraft gun area, and the speed of the helicopter will be a safe speed for the terrain, probably 50 to 75 knots. When the helicopter reaches a prescribed range from the guns, it will break away to the left or to the right, turning at the maximum safe acceleration, and will exit the area flying nap-of-earth to take advantage of the local terrain. Attack routes should be selected to control the duration of exposure before breakaway. The moving fire tactic represents one method of delivering TOW and HELLFIRE missiles. Since exposure time after breakaway is not controlled in the test, the tactic is most directly applicable to the launch-and-leave HELLFIRE.

The fourth tactic is *nap-of-earth fly-by*. This is flight on a straight course at altitudes below 5 meters (skid height AGL) and at maximum safe speed. This tactic would be used operationally when traveling near a region that contains enemy antiaircraft guns.

For both the moving fire and nap-of-earth fly-by tactics, a procedure similar to that outlined for the popup tactics should be employed so that all guns are able to fire on most trials.

For the two popup maneuvers, the factor *distance* is the distance of the popup position from the guns. Distances of

2 and 3 km span the ranges for normal use of the TOW antiarmor missile. The developmental HELLFIRE missile could be used at distances greater than 3 km, but greater ranges are of little interest for the purpose of validating models. A distance of 1 km is included so that the effect of distance can be better determined. It does not correspond to doctrine for the employment of attack or observation helicopters.

For the moving fire tactic, *distance* is the distance to breakaway. Here again, 2 and 3 km are in the range of normal use, and 1 km is included to permit the effect of distance to be better determined. For the nap-of-earth fly-by tactic, *distance* is the offset distance (i.e., the minimum horizontal distance from the gun to the helicopter track).

The remaining factor in Table 2, *firing*, has two levels. *Nonfiring* means that the guncrew merely pretends to fire; *firing* means that the guncrew fires breakup ammunition. On any one day of testing, all trials are firing or all are nonfiring. This should simplify logistics as well as ensure that prescribed test conditions will always be met with respect to this factor. The nonfiring level is included here and in Table 3 to permit one to evaluate the importance of firing on the test results. If firing is not important, future testing can presumably be conducted at lower cost with no firing.

An attack helicopter (AH-1 COBRA) should be used for the popup tactics and the moving fire tactic. A light observation helicopter (LOH) is presumed to be operating in support of the AH. The presence of the LOH may affect gun reaction time. This is permissable. However, if any gun fails to bring fire against the AH, the trial must be repeated. A single LOH should be used for the nap-of-earth fly-by tactic.

Table 3 gives the factors and levels for an experiment with fixed-wing aircraft that is directed principally at determining the influence of firing as opposed to merely pretending to fire

and the influence of multiple aerial targets on the performance of the guns and guncrews. The factor *tactics* is at four levels. The first two levels employ a single fixed-wing aircraft. Levels 3 and 4 employ a flight of four aircraft. The level 1 tactic calls for a single aircraft in straight and level flight at 450 knots at an altitude of 500 meters. This tactic might be used by a "fast FAC" or by a reconnaissance aircraft. Probabilities of hit for this tactic are expected to be much larger than those for the other tactics. In level 2 a single aircraft performs a maneuver like any one of the aircraft in levels 3 and 4. The basic maneuver employed in levels 2, 3, and 4 is one of the maneuvers from Table 1. It is a 450-knot, 45-degree dive with a 5-g breakaway initiated 1.5 km from the "target" of the aircraft and with an up-helix exit maneuver. In level 3, *curvilinear*, the four aircraft attack their "target" essentially in trail but with deliberate lateral motion between aircraft. This tactic is used to confuse gunners while retaining enough separation between aircraft to avoid having one aircraft hit by a projectile aimed at another aircraft. In level 4, *wagon wheel*, the aircraft approach the area of their target in trail but they space their roll-in (turn toward their target) so that they approach their target on different headings. Both of these multiaircraft tactics permit several aircraft to attack their target in a short interval of time so that the defenses have little or no opportunity to fire at more than one aircraft. Comparison of levels 3 and 4 with level 2 shows the effect of multiple aircraft relative to single aircraft.

C. THE EXPERIMENTAL DESIGN

Table 4 shows the experimental design corresponding to the factors and levels of Table 1. There are eight factors, seven at two levels and one at four levels--a total of 512 possible factor combinations. A quarter-replicate consisting of 128

Table 4. EXPERIMENTAL DESIGN--FIXED-WING SINGLE AIRCRAFT, FIRING

1	2	3	4	5	6	7	B
C F[a] 1 2	C F 2 1	C F 3 2	C F 4 1	C F 1 2	C F 2 1	C F 3 1	C F 4 2
(1) A B D E H S 2 2 1 2 2 2	(2) A B D E H S 2 2 2 1 1 2	(1) A B D E H S 1 1 2 1 2 2	(2) A B D E H S 1 1 1 2 1 2	(2) A B D E H S 2 1 2 2 1 1	(2) A B D E H S 2 1 1 1 2 1	(1) A B D E H S 2 2 1 2 2 1	(1) A B D E H S 2 2 2 1 1 1
(2) A B D E H S 2 2 2 2 1 2	(3) A B D E H S 2 1 2 1 1 1	(2) A B D E H S 1 1 1 1 1 2	(3) A B D E H S 1 2 1 2 1 1	(3) A B D E H S 2 1 1 2 2 1	(3) A B D E H S 2 2 1 1 2 2	(2) A B D E H S 2 1 1 2 2 2	(3) A B D E H S 2 2 1 1 2 1
(3) A B D E H S 2 1 2 1 2 2	(4) A B D E H S 2 1 1 2 1 2	(4) A B D E H S 1 2 1 2 2 2	(4) A B D E H S 1 1 1 1 2 1	(4) A B D E H S 2 2 1 1 1 1	(4) A B D E H S 2 2 2 2 2 1	(5) A B D E H S 2 1 2 1 2 1	(4) A B D E H S 2 1 1 2 1 1
(4) A B D E H S 1 2 1 1 2 2	(6) A B D E H S 1 2 2 2 1 2	(5) A B D E H S 2 2 1 2 1 1	(6) A B D E H S 2 1 1 1 1 2	(5) A B D E H S 1 1 2 1 1 1	(7) A B D E H S 1 1 1 2 2 1	(7) A B D E H S 1 2 1 1 2 1	(5) A B D E H S 1 2 2 2 1 1
(6) A B D E H S 2 1 1 1 1 2	(7) A B D E H S 2 2 1 2 1 1	(8) A B D E H S 1 2 2 2 1 2	(1D) A B D E H S 1 [illegible] 2 1 1 1	(9) A B D E H S 2 2 2 1 2 1	(B) A B D E H S 2 1 2 2 2 2	(1D) A B D E H S 2 1 1 1 1 1	(6) A B D E H S 2 2 1 2 1 2
(8) A B D E H S 1 2 2 2 2 1	(8) A B D E H S 1 2 1 1 1 1	(11) A B D E H S 2 1 1 1 2 1	(11) A B D E H S 2 2 1 2 2 2	(1D) A B D E H S 1 1 1 2 1 2	(1D) A B D E H S 1 1 2 1 2 2	(12) A B D E H S 1 1 1 2 1 1	(7) A B D E H S 1 2 1 1 1 2
(13) A B D E H S 1 1 1 1 2 1	(9) A B D E H S 1 1 2 2 1 1	(12) A B D E H S 2 1 1 2 1 2	(12) A B D E H S 2 1 2 1 2 2	(12) A B D E H S 1 2 2 1 1 2	(12) A B D E H S 1 2 1 2 2 2	(13) A B D E H S 1 2 2 1 1 1	(12) A B D E H S 1 1 2 2 1 2
(14) A B D E H S 1 2 1 2 1 1	(1D) A B D E H S 1 2 2 1 2 1	(14) A B D E H S 2 1 2 1 1 1	(13) A B D E H S 2 1 1 2 2 1	(14) A B D E H S 1 1 2 2 2 2	(14) A B D E H S 1 1 1 1 1 2	(14) A B D E H S 1 2 1 2 1 2	(13) A B D E H S 1 1 1 1 1 1

NOTE: Table 1 lists the factor levels and defines the symbols used here. This design is a one-fourth replicate consisting of 128 trials. The numbers in parentheses are sequence numbers for each day. The missing sequence numbers are in Table 5. Trials from Tables 4 and 5 are intermixed on each day of testing.

[a]The crew and fatigue levels apply to the entire column.

Table 4 (Continued)

9	1D	11	12	13	14	1S	16
C F 1 1	C F 2 2	C F 3 2	C F 4 1	C F 1 1	C F 2 2	C F 3 1	C F 4 2
(2) A B D E H S 1 2 1 1 1 2	(1) A B D E H S 1 2 2 2 2 2	(3) A B D E H S 1 2 1 1 1 1	(1) A B D E H S 1 2 2 2 2 1	(2) A B D E H S 1 1 2 1 2 1	(1) A B D E H S 1 1 1 2 1 1	(2) A B D E H S 2 1 2 2 1 2	(1) A B D E H S 2 1 1 1 2 2
(3) A B D E H S 1 1 1 1 1 1	(2) A B D E H S 1 2 1 2 1 2	(5) A B D E H S 1 2 2 1 2 1	(2) A B D E H S 1 1 2 2 2 2	(4) A B D E H S 1 2 2 1 2 2	(3) A B D E H S 1 1 2 2 2 1	(5) A B D E H S 2 2 2 2 1 1	(2) A B D E H S 2 1 2 1 1 2
(5) A B D E H S 1 2 1 2 2 1	(4) A B D E H S 1 2 2 1 1 1	(6) A B D E H S 1 1 2 2 1 1	(S) A B D E H S 1 2 2 1 1 2	(S) A B D E H S 1 1 2 2 1 2	(4) A B D E H S 1 1 1 1 2 2	(7) A B D E H S 2 2 1 1 1 2	(3) A B D E H S 2 2 2 2 2 2
(7) A B D E H S 2 1 2 2 2 1	(6) A B D E H S 2 2 2 1 2 2	(7) A B D E H S 2 1 2 2 2 2	(6) A B D E H S 2 2 2 1 2 1	(9) A B D E H S 2 2 1 2 1 2	(6) A B D E H S 2 1 1 1 1 1	(9) A B D E H S 1 1 2 1 1 2	(S) A B D E H S 1 1 1 2 2 2
(9) A B D E H S 1 2 2 2 1 1	(7) A B D E H S 1 1 2 1 1 2	(1D) A B D E H S 1 1 1 2 2 1	(9) A B D E H S 1 2 1 1 2 2	(11) A B D E H S 1 1 1 2 2 2	(B) A B D E H S 1 2 1 1 2 1	(11) A B D E H S 2 2 2 1 2 2	(6) A B D E H S 2 1 2 2 2 1
(11) A B D E H S 2 2 2 1 1 1	(8) A B D E H S 2 1 2 2 1 2	(11) A B D E H S 2 2 2 1 1 2	(1D) A B D E H S 2 1 2 2 1 1	(12) A B D E H S 2 1 1 1 2 2	(9) A B D E H S 2 2 1 2 2 1	(12) A B D E H S 1 2 2 2 2 2	(12) A B D E H S 1 1 2 1 2 1
(13) A B D E H S 2 1 1 2 1 1	(9) A B D E H S 2 1 2 1 2 1	(12) A B D E H S 2 2 2 2 2 1	(13) A B D E H S 2 2 1 1 1 1	(13) A B D E H S 2 2 2 2 2 2	(12) A B D E H S 2 2 1 1 1 2	(13) A B D E H S 1 1 1 1 2 2	(13) A B D E H S 1 2 1 2 2 1
(14) A B D E H S 2 1 2 1 1 2	(11) A B D E H S 2 2 2 2 1 1	(14) A B D E H S 2 2 1 1 2 2	(14) A B D E H S 2 2 2 2 1 2	(14) A B D E H S 2 2 1 1 2 1	(14) A B D E H S 2 1 1 2 2 2	(14) A B D E H S 1 1 2 2 2 1	(14) A B D E H S 1 2 2 1 2 2

trials has been selected for observation. This allows the estimation of all main effects and all two-factor interactions while providing 8 blocks of 16 trials each. A special effort has been made to gain precision by "blocking" the trials into groups in order to control for time of day and daily experience. The 8 blocks of 16 trials translates into 16 days of testing with 8 trials per day, as shown in Table 4. The order of testing on each day is important; the first trials of all 16 days will constitute one block, the second trials a second block, etc.

Note in the first row (heading row) of Table 4 that each crew is scheduled every fourth day so that experience retention distributions should be similar. The fatigue factor is at the second level (tired) for two out of every four trial days so that demand for "fatiguing procedures" will be approximately uniform over the trials. The selected quarter-replicate, the crew labels, and the block order have been randomized. The factor labels have been effectively randomized--they were assigned alphabetical labels to aid in their identification (e.g., F for fatigue). Because the heading row of the table identifies the crew and the fatigue level, the interior of the table lists only the remaining factors.

Table 5 presents the firing part of the experimental design that corresponds to Table 2. These rotary-wing trials are arranged in 16 columns of 6 trials each. The columns are intended to correspond to the same days as the columns of Table 4. It is assumed that the eight trials in a column of Table 4 and the six trials of the corresponding column of Table 5 can all be conducted on the same day. The order of the fixed-wing trials and the order of the rotary-wing trials should be maintained,[1]

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[1]This will preserve much of the blocking of the fixed-wing trials and will retain the randomization of the rotary-wing trials.

Table 5. EXPERIMENTAL DESIGN--ROTARY-WING AIRCRAFT, FIRING

1	2	3	4	5	6	7	8
C_1 F_2	C_2 F_1	C_3 F_2	C_4 F_1	C_1 F_2	C_2 F_1	C_3 F_1	C_4 F_2
(5) T_3 K_3	(1) T_3 K_1	(3) T_3 K_3	(1) T_4 K_2	(1) T_3 K_1	(1) T_2 K_1	(3) T_1 K_1	(2) T_2 K_3
(7) T_2 K_2	(5) T_4 K_3	(6) T_3 K_1	(5) T_2 K_1	(6) T_1 K_2	(5) T_4 K_1	(4) T_3 K_1	(8) T_2 K_3
(9) T_1 K_3	(11) T_2 K_3	(7) T_1 K_3	(7) T_1 K_3	(7) T_2 K_1	(6) T_3 K_3	(6) T_2 K_3	(9) T_4 K_2
(10) T_4 K_2	(12) T_1 K_1	(9) T_2 K_2	(8) T_3 K_3	(9) T_4 K_3	(8) T_1 K_3	(10) T_3 K_2	(8) T_3 K_1
(11) T_4 K_1	(13) T_3 K_2	(10) T_4 K_2	(9) T_3 K_1	(11) T_3 K_2	(11) T_2 K_2	(9) T_4 K_3	(11) T_2 K_1
(12) T_1 K_1	(14) T_1 K_2	(13) T_1 K_1	(14) T_1 K_2	(13) T_2 K_3	(13) T_4 K_2	(11) T_2 K_2	(14) T_1 K_2

9	10	11	12	13	14	15	16
C_1 F_1	C_2 F_2	C_3 F_2	C_4 F_1	C_1 F_1	C_2 F_2	C_3 F_1	C_4 F_2
(1) T_2 K_1	(3) T_2 K_2	(1) T_1 K_2	(3) T_2 K_2	(1) T_2 K_3	(2) T_3 K_2	(1) T_3 K_2	(4) T_3 K_2
(4) T_1 K_2	(5) T_1 K_1	(2) T_2 K_3	(4) T_4 K_1	(3) T_4 K_2	(5) T_3 K_3	(3) T_4 K_1	(7) T_2 K_2
(6) T_3 K_2	(10) T_1 K_3	(4) T_3 K_2	(7) T_3 K_2	(6) T_1 K_1	(7) T_4 K_1	(4) T_3 K_3	(8) T_4 K_3
(12) T_4 K_3	(8) T_3 K_1	(8) T_4 K_1	(8) T_2 K_3	(7) T_3 K_3	(10) T_2 K_1	(6) T_1 K_3	(9) T_4 K_1
(10) T_1 K_3	(13) T_4 K_3	(9) T_2 K_1	(11) T_1 K_1	(8) T_2 K_2	(11) T_2 K_3	(8) T_1 K_2	(10) T_1 K_1
(12) T_3 K_1	(14) T_4 K_2	(13) T_4 K_3	(12) T_4 K_3	(11) T_1 K_1	(13) T_1 K_2	(10) T_2 K_1	(11) T_1 K_3

NOTE: Table 2 lists the factor levels and explains the symbols. The corresponding nonfiring trials are presented in Table 6. The numbers in parentheses are sequence numbers (see Table 4).

but the rotary-wing trials should be interspersed at random among the fixed-wing trials so that guncrews do not know which type aircraft they will encounter next. The numbers in parentheses in Tables 4 and 5 are sequence numbers that provide an appropriate ordering of trials for each day of testing.

The nonfiring part of the experimental design corresponding to Table 2 is shown in the lower part of Table 6. These rotary-wing trials are a full replicate of a reduced design (i.e., the second level of distance, K_2, does not appear). There are 64 trials grouped into 8 columns of 8 trials each. The columns are intended to correspond to days of testing. The rotary-wing trials in Tables 5 and 6 have not been blocked. Instead they have been randomized separately on each day.

The nonfiring portion of the design for Table 3 is given in the upper part of Table 6. The fixed-wing trials and rotary-wing trials in each column of Table 6 should be conducted on the same day. The order of fixed- and rotary-wing trials in any day should be maintained, but the fixed- and rotary-wing trials should be interspersed in a random fashion. The sequence numbers in Table 6 provide such a random ordering of trials.

The firing portion of the design for Table 3 will be performed on four additional days, as described in Table 7. These days can also be used to make up missed or invalid firing trials for the experiment described in Tables 4 and 5. Care should be taken to schedule these makeup trials so that they occur in approximately the same daily position as called for in the original schedule. Thus, they should be inserted first, and the trials described in Table 7 should be scheduled around them. Note that the Table 7 trials have not been blocked. It is assumed that the complexity of the factor *tactics* will diminish the daily learning factor, and they have been suitably randomized.

Table 6. EXPERIMENTAL DESIGN--FIXED- AND ROTARY-WING AIRCRAFT, NONFIRING

1	2	3	4	5	6	7	8
$C_1 F_2$	$C_2 F_1$	$C_3 F_2$	$C_4 F_1$	$C_1 F_1$	$C_2 F_2$	$C_3 F_1$	$C_4 F_2$
FIXED-WING							
(2) $T_4 H_2$	(2) $T_4 H_2$	(1) $T_2 H_2$	(1) $T_4 H_2$	(1) $T_2 H_1$	(1) $T_2 H_1$	(3) $T_1 H_2$	(1) $T_3 H_2$
(4) $T_2 H_1$	(3) $T_4 H_1$	(3) $T_4 H_2$	(2) $T_2 H_1$	(2) $T_4 H_2$	(2) $T_2 H_2$	(4) $T_2 H_1$	(2) $T_3 H_1$
(5) $T_1 H_2$	(6) $T_2 H_2$	(5) $T_4 H_1$	(5) $T_1 H_1$	(3) $T_1 H_2$	(3) $T_3 H_1$	(6) $T_3 H_2$	(3) $T_4 H_2$
(6) $T_1 H_1$	(7) $T_2 H_1$	(7) $T_3 H_1$	(8) $T_3 H_2$	(7) $T_3 H_2$	(4) $T_1 H_1$	(7) $T_2 H_2$	(7) $T_1 H_2$
(7) $T_4 H_1$	(8) $T_3 H_1$	(9) $T_3 H_2$	(9) $T_4 H_1$	(9) $T_4 H_1$	(7) $T_1 H_2$	(11) $T_4 H_2$	(8) $T_2 H_1$
(8) $T_3 H_2$	(9) $T_3 H_2$	(10 $T_1 H_2$	(11) $T_3 H_1$	(12) $T_3 H_1$	(8) $T_4 H_2$	(12) $T_1 H_1$	(11) $T_2 H_2$
(9) $T_2 H_2$	(11) $T_1 H_1$	(13) $T_2 H_1$	(13) $T_1 H_2$	(14) $T_2 H_2$	(9) $T_4 H_1$	(13) $T_3 H_1$	(15) $T_1 H_1$
(11) $T_3 H_1$	(14) $T_1 H_2$	(15) $T_1 H_1$	(16) $T_2 H_2$	(16) $T_1 H_1$	(10) $T_3 H_2$	(14) $T_4 H_1$	(16) $T_4 H_1$
ROTARY-WING							
(1) $T_3 K_3$	(1) $T_1 K_3$	(2) $T_2 K_1$	(3) $T_1 K_3$	(4) $T_2 K_1$	(5) $T_3 K_3$	(1) $T_2 K_1$	(4) $T_3 K_3$
(3) $T_4 K_3$	(4) $T_3 K_1$	(4) $T_2 K_3$	(4) $T_3 K_1$	(5) $T_1 K_1$	(6) $T_4 K_1$	(2) $T_4 K_1$	(5) $T_3 K_1$
(10) $T_1 K_3$	(5) $T_3 K_3$	(6) $T_4 K_1$	(6) $T_2 K_3$	(6) $T_2 K_3$	(11) $T_2 K_1$	(5) $T_3 K_1$	(6) $T_4 K_3$
(12) $T_4 K_1$	(10) $T_4 K_1$	(8) $T_1 K_1$	(7) $T_3 K_3$	(8) $T_3 K_3$	(12) $T_3 K_1$	(8) $T_1 K_1$	(9) $T_1 K_1$
(13) $T_1 K_1$	(12) $T_2 K_3$	(11) $T_3 K_1$	(10) $T_2 K_1$	(10) $T_4 K_3$	(13) $T_2 K_3$	(9) $T_3 K_3$	(10) $T_4 K_1$
(14) $T_2 K_3$	(13) $T_2 K_1$	(12) $T_4 K_3$	(12) $T_4 K_1$	(11) $T_2 K_1$	(14) $T_1 K_3$	(10) $T_4 K_3$	(12) $T_2 K_3$
(15) $T_2 K_1$	(15) $T_1 K_1$	(14) $T_3 K_3$	(14) $T_1 K_1$	(13) $T_4 K_1$	(15) $T_4 K_3$	(15) $T_2 K_3$	(13) $T_1 K_3$
(16) $T_3 K_1$	(16) $T_4 K_3$	(16) $T_1 K_3$	(15) $T_1 K_3$	(15) $T_4 K_3$	(16) $T_1 K_3$	(16) $T_1 K_1$	(14) $T_2 K_1$

NOTES: The fixed-wing trials are the nonfiring part of the design corresponding to the factor levels in Table 3. These 64 trials provide two trials for each set of nonfiring conditions in Table 3.

The rotary-wing trials are the nonfiring part of the design corresponding to the factor levels in Table 2. These are a full replicate of 64 nonfiring trials with K_2 not in the design. Table 5 is a full replicate of 96 firing trials with distance at all three levels--K_1, K_2, and K_3.

Table 7. EXPERIMENTAL DESIGN--FIXED-WING AIRCRAFT, FIRING

1	2	3	4
C_1 F_1	C_2 F_1	C_3 F_1	C_4 F_1
T_3 H_1	T_4 H_1	T_1 H_1	T_1 H_1
T_1 H_1	T_2 H_2	T_1 H_2	T_2 H_1
T_3 H_2	T_1 H_1	T_3 H_1	T_3 H_2
T_4 H_1	T_1 H_2	T_2 H_2	T_3 H_1
T_1 H_2	T_3 H_2	T_4 H_2	T_4 H_1
T_2 H_1	T_4 H_2	T_3 H_2	T_2 H_2
T_2 H_2	T_2 H_1	T_2 H_1	T_1 H_2
T_4 H_2	T_3 H_1	T_4 H_1	T_4 H_2

Note: These trials are the firing part of the design corresponding to Table 3. These 32 trials are a full replicate of the firing trials.

Chapter III

DATA REQUIREMENTS AND MAJOR INSTRUMENTATION

This chapter lists the specific data elements that must be obtained from the test and the necessary range and accuracy of each measurement. It also places limits on the errors of particular portions of the instrumentation system, and it describes an instrumentation approach for measuring aerial target position and gun tilt.

The stringent accuracy requirements in the measurement of the gun pointing angles and the position of the aerial target result from the need to know precisely the mean trajectory of a projectile relative to the target position. Knowing this trajectory will allow computation of the mean miss vector. This mean miss vector should be measured with a total error of less than 0.1 percent of the range from the guns.[1] This total error must include all errors that persist for more than a few rounds (autocorrelated errors). Errors that are uncorrelated from round to round have much less influence on the probability of hit for an engagement than autocorrelated errors have. Consequently, the accuracy requirements stated in this chapter should be interpreted to include all error components that are autocorrelated with time constants greater than 0.2 second.[2] However,

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[1]The error then would appear as less than a 1-mrad error measured from the gun position (WSEG Report 190, op. cit.). WSEG Report 190 also shows that a 0.4-percent error in range from a gun is roughly equivalent to a 1-mrad angular error at the gun in terms of its effect on the mean miss vector.

[2]That is, the correlation coefficient between the error at a particular time and the error 1 second earlier should not exceed e^{-5} for any error classified as being uncorrelated.

because the errors will change throughout an encounter (with time and geometry), one is justified in using the root sum square of the components as an indicator of overall error. Also, since azimuthal and elevation angular errors are mutually perpendicular, the total accuracy requirement should be met for azimuth and elevation separately; the azimuth and elevation errors should not be combined.

In addition to meeting the accuracy requirements, the instrumentation should not interfere with the desired operational test environment. The aircraft should be free to perform maneuvers within a 15-km-radius circular area from ground level to an altitude of approximately 7 km AGL at speeds up to 300 meters per second and accelerations up to 6 g's. The guns should be free to engage the aircraft without interference from the test instrumentation.

To properly control the test, it will be necessary to have separate communications nets for air traffic control and for test personnel (test controllers, instrumentation operators, and data gatherers). A separate communications net for guncrews may be needed to add tactical realism. The Test Director and his operations staff should be able to monitor all nets. They should be able to communicate directly with test personnel, with guncrews and, through an air traffic controller, with aircrews.

A. GENERAL DATA REQUIREMENTS

Position and direction information will be presented with respect to a reference coordinate system (RCS). The RCS will have an arbitrary origin in the vicinity of the guns or instrumentation radar systems. The RCS will be a right-hand cartesian coordinate system with the X axis directed to the east, the Y axis to the north, and the Z axis upward. Positions of guns, radars, fire directors, and aerial targets will be presented in

cartesian coordinates with respect to the RCS. Directions[1] will be presented in spherical coordinates with the azimuth angle measured in the horizontal plane counterclockwise from the X axis and with the elevation angle measured in a vertical plane upward from the horizontal plane. The basic units of measure for position will be meters (m); those for direction, milliradians (mrad).

The measurements of quantities that vary during a trial will be coordinated with Inter-Range Instrumentation Group time. The IRIG time at which each measurement is made will be recorded to the nearest millisecond or better. Required data rates stated in Section B are the frequencies of the data presented after initial data processing. The rate at which the measurements are made can differ from the required data rate, but must be high enough so that the subsequent smoothing and interpolating do not cause the total error in presented data to exceed the limits stated in specific data requirements.

Unless noted otherwise, presented data will be synchronized. That is, if the position of the aerial target and the pointing direction of a gun are both presented at 0.1-second intervals, they will be presented for exactly the same times.

All data will be presented on magnetic tape after appropriate processing. The processing will include (but need not be limited to) (1) measuring the coordinates of images on photographic film, (2) applying calibration corrections, (3) smoothing and interpolating data, (4) performing coordinate transformations to the RCS, (5) digitizing data from strip recorders and a voice recording system, and (6) converting from the units of original measurements to those of presented data. The magnetic tapes must be compatible with the Control Data Corporation Model 6400 computer system at IDA. File lengths, record

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[1]For example, the direction of an aerial target from an optical sight or a radar.

lengths, recording densities, bit codes, and formats must be determined by coordination with WSEG/IDA personnel. These magnetic tapes will be delivered to WSEG/IDA.

All raw data will also be delivered to WSEG/IDA. Included will be all photographic data, strip recorder data, voice recording system tapes, and manually recorded data. Before delivery to WSEG/IDA, all original magnetic tapes of digital data will be duplicated in a format that can be read on IDA's CDC 6400.

With the exception of data derived from photographs, all data from a trial will be delivered to WSEG/IDA within 2 weeks of the trial. Data derived from photographs will be delivered within 6 weeks of the trial. With regard to dry runs prior to the test, data derived from photographs will be delivered within 1 week; all other data will be delivered within 2 days.

B. SPECIFIC DATA REQUIREMENTS

1. Requirements Independent of Gun Type

The trials are expected to be grouped into test periods of about 2 hours' duration. Before each test period and at intervals of 3 hours or less, the following atmospheric data will be recorded: pressure and temperature at ground level, wind speed and direction, cloud cover, ceiling, and visibility.

For every trial and for every gun, the following will be recorded: gun type, gun location, guncrew number, identity of any substitute guncrew members, identity of the test controller, any condition that would render the trial invalid (such as failure to detect the aerial target), and general comments of the controller.

The position, velocity, and acceleration of each aerial target will be measured and coordinated with IRIG time. The rate for recording these data will be 10 per second during the period of each trial specified as follows: The data for

fixed-wing aircraft should be available for the entire period when the aircraft is (are) within 10 km of the guns. The data for rotary-wing aircraft should be available from hover before unmask until hover after remask and throughout the straight passes and nap-of-earth passes when within 4 km of the guns. Accuracy requirements for aircraft position data are given in Section D. Velocity and acceleration data will be the best that can be derived from the position data.

The orientation angles of all rotary-wing aircraft will be required during the periods when position is being measured. These angles should be presented to an accuracy of 50 mrad at a data rate of 10 per second. Orientation angles are desirable for fixed-wing aircraft also. However, these data can be approximately derived from the aircraft position data; hence, elaborate or expensive special instrumentation to measure the angles is not justified for the fixed-wing aircraft.

2. Requirements by Gun Type

The field test will measure the reaction time of each gun on each trial so that the distribution of reaction time and the dependence of reaction time on the initial misalignment of the gun can be determined. *Reaction time* is defined for this test as the difference between the time of first detection of an aerial target by a gun system and the earliest time that the gun system could begin firing at the target. Thus, reaction time will be derived from time of first target detection and time of possible open fire, regardless of when firing actually begins.

First target detection is the initial detection of the target by any guncrew member. Detection can be visual or (with some systems) by radar. It is probable that fixed-wing aircraft will be detected well beyond maximum firing range by the two gun systems that use radar. These same systems may also detect

rotary-wing aircraft shortly after unmask. However, at least for the two gun systems that must rely on visual detection, it is expected that there will be trials in which the guncrew would never detect the aircraft, or would not detect them in time to fire. While this may be of interest for other purposes, such trials would not yield data relevant to guns firing at aircraft and would have to be repeated. Chapter II, Section B, describes separate procedures for fixed-wing trials and rotary-wing trials to avoid excessive repetition. It is suggested there that the test controller at a gun should aid the guncrew when it appears that they would otherwise fail to detect the aircraft early enough to fire. At any time a guncrew is aided in this way, the time of first target detection is the time that the target is pointed out by the controller. The controller must then be recorded as the person detecting the target so that such trials can be identified.

Reaction time of a gun system may be a function of the angle between the azimuth of the gun and the azimuth of the target from the gun at the time of detection. An initial gun azimuth will be specified for each trial in an attempt to determine the influence of initial azimuthal misalignment on reaction time. Specifying initial azimuth may also provide a degree of control over visual detection of targets.

Time of possible open fire is the first time that a gun system could fire at an aerial target. For the ZU-23 and the S-60 using optical-mechanical fire control systems, time of possible open fire is defined for this test as the first time that the angular tracking error is below 20 mrad and the four inputs to the fire control computer have all been adjusted or all fall within the following regions about their true values: speed of fixed-wing aerial targets, ±100 knots; speed of rotary-wing aerial targets, ±50 knots; target course angle, ±300 mrad; target climb or dive angle, ±300 mrad; target range, -50 to +100 percent of true range. For the S-60 using the PUAZO 6-60 fire

director and the SON-9 radar, the time of possible open fire is the time that the firing solution indicator light on the fire director comes on. There is a similar indicator that can be used for time of possible open fire on the 5PFZ-B.

Time of fire is defined as the time a projectile leaves the muzzle.

Specific data requirements will now be presented by gun type. Data will be required at the rates specified from the time that a fixed-wing target is detected until it passes out of sight or is beyond the following ranges from the guns: 3 km for the ZU-23, 6 km for the S-60s, and 4 km for the 5PFZ-B. Data will be required at the rates specified from the time that a rotary-wing target is detected until it masks to end the trial or is more than 4 km from the guns.

a. Twin 23mm Antiaircraft Gun, ZU-23

The ZU-23 is a light antiaircraft weapon consisting of two 23mm guns with an on-carriage optical-mechanical fire control system. The data elements listed in Table 8 will be measured and coordinated with IRIG time.

b. Single 57mm Antiaircraft Gun, S-60

The S-60 will be tested in two configurations: (1) the S-60 gun with an optical-mechanical fire control system and (2) the S-60 gun, a PUAZO 6-60 fire director with integral optical sights, and a SON-9 radar. The first configuration has a fire control system similar to that of the ZU-23; the second, which will be called the S-60 with fire director, can operate in several modes. The mode to be tested uses angular tracking by the optical sights on the director and uses range tracking by the radar.

The data elements listed in the top section of Table 9 will be measured and coordinated with IRIG time for both S-60 configurations; those in the middle section, only for the S-60 with

optical-mechanical fire control system; and those in the bottom section, only for the S-60 with fire director.

Table 8. DATA ELEMENTS, ZU-23

Data Element	Data Rate	Range	Accuracy
Specified initial gun azimuth	once[a]	0 to 360°	20 mrad
Target mask condition	10/sec	masked & unmasked	--
Target detection time	once	--	1 sec
Crewman detecting target	once	--	
Time of possible open fire	once	--	1 sec
Time of fire of each round[b]	--	--	1 msec
Gun pointing angles relative to base:			
Azimuth	10/sec	0 to 360°	0.4 mrad
Elevation	10/sec	-10 to +90°	0.4 mrad
Tilt of gun base:			
Azimuth	10/sec[c]	-20 to +20 mrad	0.6 mrad
Elevation	10/sec[c]	-20 to +20 mrad	0.6 mrad
Angular tracking errors of the optical sight:			
Azimuth	20/sec	-100 to +100 mrad	1 mrad
Elevation	20/sec	-100 to +100 mrad	1 mrad
Inputs to the fire control system:			
Speed	10/sec	0 to 330 m/sec	1 m/sec
Course angle	10/sec	0 to 360°	4 mrad
Climb or dive angle[d]	10/sec	-90 to +90°	4 mrad
Range	10/sec	0 to 3,300 m	50 m

[a]Once per trial.

[b]There are also nonfiring trials. In these, the time that the firing pedal is depressed and the time it is released must be recorded to the nearest tenth of a second.

[c]This quantity is also required at the precise time of fire of each round.

[d]Climb is defined as positive; dive, as negative.

Table 9. DATA ELEMENTS, S-60

Data Element	Data Rate	Range	Accuracy
BOTH S-60 CONFIGURATIONS			
Specified initial gun azimuth	once	0 to 360°	20 mrad
Target mask condition	10/sec	masked & unmasked	--
Target detection time	once	--	1 sec
Crewman detecting target	once	--	
Time of possible open fire	once	--	1 sec
Time of fire of each round[a]	--	--	1 msec
Gun pointing angles relative to base:			
Azimuth	10/sec	0 to 360°	0.4 mrad
Elevation	10/sec	-4 to +87°	0.4 mrad
Tilt of gun base:			
Azimuth	10/sec[b]	-20 to +20 mrad	0.6 mrad
Elevation	10/sec[b]	-20 to +20 mrad	0.6 mrad
S-60 WITH OPTICAL-MECHANICAL FIRE CONTROL SYSTEM			
Angular tracking errors of the optical sight:			
Azimuth	20/sec	-100 to +100 mrad	1 mrad
Elevation	20/sec	-100 to +100 mrad	1 mrad
Inputs to the fire control system:			
Speed	10/sec	0 to 300 m/sec	1 m/sec
Course angle	10/sec	0 to 360°	4 mrad
Climb or dive angle	10/sec	-90 to +70°	4 mrad
Range	10/sec	0 to 5,500 m	50 m
S-60 WITH FIRE DIRECTOR			
Radar tracking data:			
Range	10/sec	0 to 20 km	10 m
Azimuth	10/sec	0 to 360°	0.5 mrad
Elevation	10/sec	-4 to 87°	0.5 mrad
Optical tracking data:			
Azimuth	20/sec	0 to 360°	0.5 mrad
Elevation	20/sec	-4 to +87°	0.5 mrad
Range input to director	10/sec	0 to 20 km	10 m
Range output of altitude unit of director	10/sec	0 to 20 km	10 m
Fire director data for target speed (3 components)	10/sec	-350 to +350 m/sec	1 m/sec
Fire director outputs (gun commands):			
Azimuth	10/sec	0 to 360°	0.4 mrad
Elevation	10/sec	-4 to +87°	0.4 mrad
Fire director settings[c]			
Muzzle velocity correction	once	-12 to +8%	visual[d]
Wind speed (2 components)	once	0 to 30 m/sec	visual
Air density	once	-20 to +20%	visual
Air temperature	once	-40 to +50°C	visual
Parallax (2 components)	once	-600 to +600 m	visual
Settling time	once	6 or 15 sec	--
Solution indication	10/sec	off or on	--

[a]There are also nonfiring trials. In these, the time that the firing pedal is depressed and the time it is released must be recorded to the nearest tenth of a second.

[b]This quantity is also required at the precise time of fire of each round.

[c]Values set by the crew into the fire director.

[d]Controller should read the setting on the fire director.

c. Twin 35mm Antiaircraft Gun, 5PFZ-B

The 5PFZ-B is a twin 35mm antiaircraft gun system mounted on a modified Leopard tank chassis. It has an S-band search radar and a K_u-band tracking radar. The tracking radar automatically locks on and tracks an aerial target that has been acquired by the search radar or optical periscopes. Stabilized periscopes are provided for observing automatic tracking and for acquiring and tracking aerial targets. A solid state analog computer calculates lead angles and super-elevation. Deviations of muzzle velocity, vehicle pitch and cant, and acceleration of the target are automatically taken into account. The weapon will use the radar tracking mode when possible.

The data elements listed in Table 10 will be measured and coordinated with IRIG time.

C. COMBINED ERRORS--HIT SCORING SYSTEM

The hit scoring system is defined as that part of the instrumentation which measures (1) the target position relative to the gun, (2) the pointing angles of the gun barrel (including tilt), and (3) the data and methodology used to compute projectile mean trajectories and dispersion. The possible errors in measuring (1) and (2) consist of the following: errors of the target tracking system; survey errors of the tracking system relative to the gun (position, azimuth reference, and vertical reference); and gun barrel pointing angle errors, including gun tilt. These include azimuth, elevation, and range errors. The error due to the time coordination of the data is negligible (IRIG time is accurate to 5 microseconds). The accuracies presented in Table 11 are consistent with the combined accuracy requirement. They constitute a recommended error budget.

Table 10. DATA ELEMENTS, 5PFZ-B

Data Element	Data Rate	Range	Accuracy
Specified initial gun azimuth	once	0 to 360°	20 mrad
Target mask condition	10/sec	masked & unmasked	--
Target detection time	once	--	1 sec
Target detection mode	once	optical or search radar	--
Time of possible open fire	once	--	1 sec
Time of fire of each round[a]	--	--	1 msec
Gun pointing angles relative to chassis:			
Azimuth	10/sec	0 to 360°	0.4 mrad
Elevation	10/sec	-10 to +85°	0.4 mrad
Tilt of chassis:			
Azimuth	10/sec[b]	-20 to +20 mrad	0.6 mrad
Elevation	10/sec[b]	-20 to +20 mrad	0.6 mrad
Search radar data:			
Detection time	once	--	0.1 sec
Azimuth of detection	once	0 to 360°	20 mrad
Range of detection	once	0 to 15 km	250 m
Tracking radar data:			
Lock-on time	once	--	0.1 sec
Range	10/sec	0.3 to 15 km	5 m
Azimuth[c]	10/sec	-96 to +96°	0.5 mrad
Elevation[c]	10/sec	-10 to +85°	0.5 mrad
Optical tracking data:			
Azimuth[c]	20/sec	0 to 360°	0.5 mrad
Elevation[c]	20/sec	-10 to +85°	0.5 mrad
Fire control computer data:			
Range	10/sec	0.3 to 10 km	5 m
Azimuth	10/sec	0 to 360°	0.5 mrad
Elevation	10/sec	-10 to +85°	0.5 mrad
Target velocity (3 components)	10/sec	-350 to +350 m/sec	1 m/sec
Fire control computer outputs (gun commands):			
Azimuth	10/sec	0 to 360°	0.4 mrad
Elevation	10/sec	-10 to +85°	0.4 mrad
Fire control computer settings:			
Muzzle velocity correction	once	-85 to +49 m/sec	1 m/sec
Wind speed	once	0 to 56 knots	visual
Wind bearing	once	0 to 360°	visual
Air pressure	once	805 to 1,085 mbar	visual
Air temperature	once	233 to 325°K	visual
Solution indication	10/sec	off or on	--

[a] There are also nonfiring trials. In these, the time that the firing pedal is depressed and the time it is released must be recorded to the nearest tenth of a second.

[b] This quantity is also required at the precise time of fire of each round.

[c] Relative to the turret, on which the tracking radar and periscopes are mounted.

Table 11. ACCURACY REQUIREMENTS OF HIT SCORING SYSTEM

Errors	Azimuth, Elevation (mrad)	Range (meters)
Aircraft positional error as measured by tracker	0.2	2
Surveyed positional error of laser tracker relative to gun (based on survey accuracy of 1/25,000)	0.04	0.2
Angular error of laser tracker relative to reference direction	0.1	--
Pointing angle errors of gun barrel including gun mount tilt	0.7	--
Angular error of gun mount relative to reference direction	0.1	--
Total combined error of instrumentation system	0.8	2

D. DETERMINATION OF TARGET POSITION

As discussed in Chapter II, both single- and multiple-aircraft passes are required for the experiments. The recommended instrumentation approaches for determining aircraft position for both situations are presented in this section.

1. Trials Corresponding to Tables 1 and 2 *(page 13)*

The purpose of the trials of Tables 1 and 2 is to obtain data for determining probability of hit by an antiaircraft gun firing at a single fixed-wing or rotary-wing aircraft. The error budget in Section C indicates that the position of the aircraft relative to the gun should be measured to an accuracy of 0.2 mrad in angle and 2 meters in range.

A laser tracker is recommended as the primary instrumentation for single-aircraft tracking data. The accuracy of the laser tracker is 0.1 mrad in azimuth and elevation and 0.3 meter in range.[1] By placing the laser tracker within 2 km of the guns, the accuracy requirement can be met except for times at which the aircraft pass close to the guns (this is acceptable). The laser tracker can track aircraft to ground level, whereas conventional instrumentation radars cannot perform precision tracking at elevation angles below about +3 degrees. Aircraft tracked by the laser tracker are required to carry a simple passive retroreflector. In the rotary-wing trials that have both an AH and an LOH, the laser tracker should track the AH. The LOH should be tracked by the laser tracker when it is in a trial alone, but when operating with an AH it should be tracked by cinetheodolites or by an AN/FPS-16 radar. Cinetheodolites or an AN/FPS-16 radar should also be used to track the AH. This will provide a degree of redundancy.

A single laser tracker, suitable for the test, is presently being constructed by GTE Sylvania under contract to TECOM, Aberdeen Proving Ground. It is scheduled for completion in May 1973 and is to be delivered to White Sands Missile Range for final checkout.

2. Trials Corresponding to Table 3 *(page 14)*

The purpose of the trials of Table 3 is to determine whether or not guncrews are confused by multiple fixed-wing targets and whether or not they perform differently when firing than when pretending to fire. For these trials, the accuracy requirement of the tracking data can be less stringent than for the other trials, although the greater accuracy is desirable if it can be achieved.

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[1]Accuracy values given here are the contractor estimates. Atmospheric refraction may reduce accuracy.

The accuracy requirement for these trials is 5 meters in each of three orthogonal directions. This requirement can be met by tracking each of the four fixed-wing aircraft by an AN/FPS-16 radar. The accuracy of the FPS-16 radar is about 0.2 mrad in azimuth and elevation and about 5 meters in range.[1] Precision tracking is limited to elevation angles above about +3 degrees.

Aircraft tracked by the FPS-16 radar are required to carry a C-band beacon for the purpose of identification. The laser tracker should track one of the aircraft for redundancy and as a check on the radar.

E. DETERMINATION OF GUN TILT

The pointing angles of antiaircraft guns will be measured by shaft-angle encoders. These devices will be installed in each weapon so as to provide measurements of azimuth and elevation angles with respect to the mount. If the mount is rigid and does not move with respect to the ground, the angle measuring devices will provide measurement of the pointing angles with respect to the ground. However, if the mount tilts, the measurements will no longer be the correct angles with respect to the ground.

A preliminary test is being conducted by the Joint Service Test Director to measure the extent to which twin 23mm and single 57mm gun mounts tilt when the guns are fired. This tilt test is being conducted at several fixed gun azimuths and elevations. However, during the field test, the gun pointing angles will be continuously changing as the aircraft is tracked. The instrumentation used in the tilt test will not be satisfactory for the field test.

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[1]RCA states that by means of a special calibration the accuracy of the FPS-16 could be increased to 0.1 mrad in angle and 1 meter in range.

In the field test, tilt should be measured about three orthogonal axes, and the measurements about these axes should be transformed into azimuth and elevation components of tilt. Three candidate systems for measuring gun mount tilt were evaluated: (1) a remote laser interferometer (Hewlett Packard), (2) the MIDARM System (Razdow Laboratories), and (3) a biaxial autocollimator (Physitech, Inc.).

Of the systems considered, the biaxial autocollimator is the best choice. The system has the required accuracy and response time, and it has the particular advantage that a single instrument will measure the angular displacement about two axes simultaneously. Two instruments can measure rotation about all three axes of the gun mount.

Because the gun will be changing azimuth during the field test, it may be necessary to place the autocollimator in a shallow trench. Figure 1 shows an autocollimator mounted on a pile to isolate the instrument from surface shock waves. A 45-degree reflector mounted on another pile directs the laser beam to a mirror attached to the underside of the gun mount. Another biaxial autocollimator would be required to measure angular displacement about the vertical gun axis; this second instrument would use a vertical mirror attached to the gun mount.

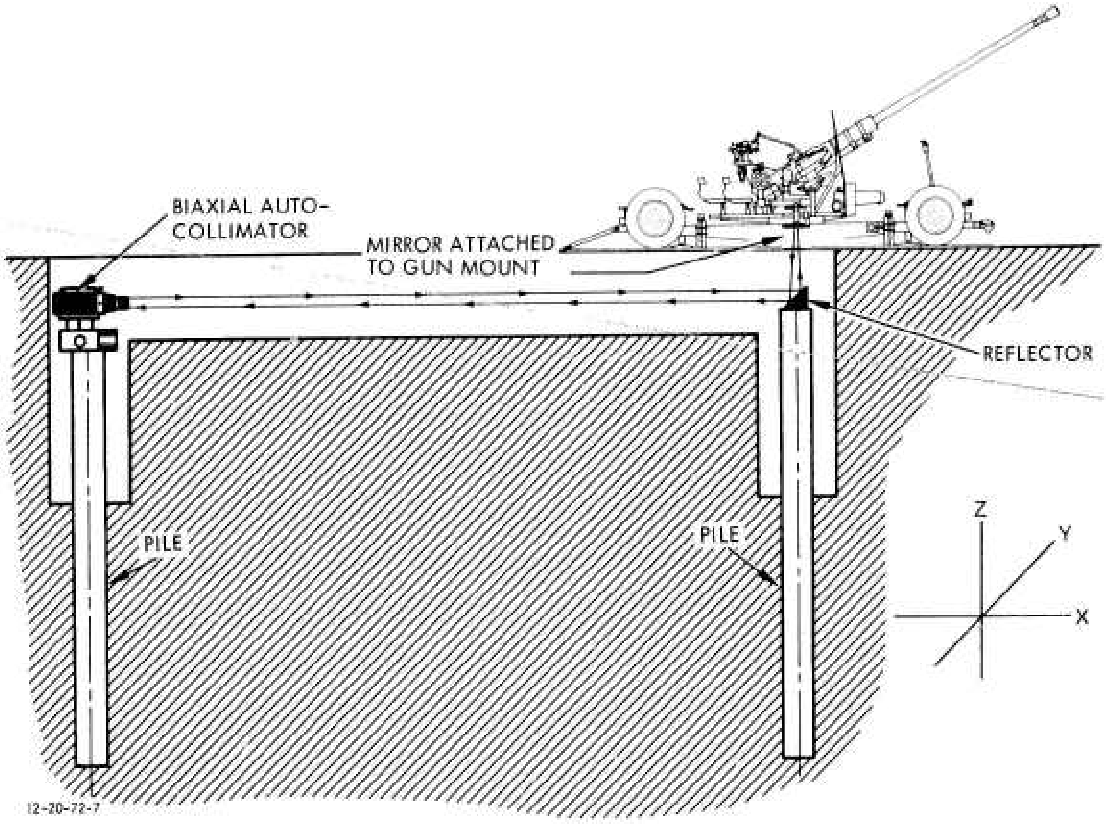

Figure 1. OPERATIONAL TILT TEST CONFIGURATION

Chapter IV

AIRCRAFT AND ANTIAIRCRAFT GUN SYSTEMS

A. AIRCRAFT SYSTEMS

Aircraft from operationally ready tactical units flown by combat-ready crews provide the most appropriate participants for these field tests. Unit readiness training requirements should be combined with field test sorties to the maximum extent possible consistent with field test conditions. Types of aircraft selected are expected to be in service with tactical units that could provide close air support during the mid-1970s.

1. Types of Aircraft

a. Fixed-Wing

The F-4 will be the principal fixed-wing aircraft for providing close air support during the mid-1970s. For field testing on or adjacent to White Sands Missile Range (WSMR), the Tactical Fighter Wing at Holloman AFB, New Mexico, would be the logical unit to provide F-4 sorties. The F-4 would fly the 450-knot trials.

If available, candidate AX aircraft currently undergoing test could be staged out of Holloman AFB to take part in the test. The addition of these aircraft would provide different airspeed, maneuver characteristics, and recognition shapes than those exhibited by the F-4. The A-37 could also be used and would provide similar variables to those cited for the AX. A detachment of A-37s from an operationally ready unit could stage out of Holloman AFB. The AX or the A-37 would fly the 300-knot trials.

b. Rotary-Wing

AH-1 COBRA and LOH aircraft performing their normal team tactical mission are required. Aircraft may be staged out of Fort Bliss, Texas, with the heliport at WSMR Headquarters area as a limited alternate.

2. Special Identifiers

All fixed- and rotary-wing aircraft will require C-band beacons (transponders) to ensure positive radar identification when tracked by FPS-16 range radars. These beacon units must be installed so as to provide a recognizable return during aircraft maneuvering. Thus, more than one beacon per aircraft may be required. These beacons must be accessible for frequency changes necessary to match scheduled mission frequencies as assigned by WSMR control.

All fixed- and rotary-wing aircraft will have laser reflectors installed for tracking purposes.[1] More than one reflector per aircraft will be required.

Normal tactical color schemes are required for all aircraft. Color coding or special high visibility paint that would provide antiaircraft guncrews unusual visual cues will not be used.

3. Numbers of Aircraft

The fixed-wing part of the test requires 176 trials with single aircraft and 48 trials with multiple aircraft, as listed in Table 12. The sortie requirement for the single-aircraft trials are computed on the following basis: The trials of Table 4 involve both the F-4 and the AX separately, and because one aircraft of each type would be required on station during

[1]On the trials with four aircraft, only one of the aircraft is required to carry the laser reflector.

Table 12. AIRCRAFT RESOURCES REQUIRED

Aircraft Category →	Fixed-Wing		Rotary-Wing
Trial Category →	Single Aircraft	Multiple (4) Aircraft	Single Aircraft
Trials			
Table Reference 4	64 F-4 64 AX	--	--
Table Reference 5	--	--	72 AH & LOH 24 LOH
Table Reference 6[a]	32 F-4	32 F-4	48 AH & LOH 16 LOH
Table Reference 7	16 F-4	16 F-4	--
Total Trials	112 F-4 64 AX 176	48 F-4	120 AH & LOH 40 LOH 160
Aircraft x Trials	112 F-4 64 AX 176	192 F-4	120 AH 160 LOH 280
Aircraft Sorties[b]	44 F-4 32 AX 76	48 F-4	48 AH 48 LOH 96
Test Missions[b]	44 F-4 32 AX 76	12 F-4	48 AH & LOH

[a]All Table 6 trials are nonfiring trials.

[b]Computation of the numbers of sorties and missions is described in the text.

the testing periods, the aircraft would average only two trials per sortie. Therefore, the trials of Table 4 would require 32 F-4 sorties and 32 AX sorties. The fixed-wing single-aircraft trials of Tables 6 and 7 would average four trials per sortie, so they require 12 F-4 sorties. The fixed-wing multiple-aircraft

trials of Tables 6 and 7 would average four trials per mission, as they require 12 missions. These missions are flights of four F-4s, so these trials require 48 F-4 sorties.

The rotary-wing part of the test requires 160 trials, 120 of which involve an AH-LOH team, and the others only the LOH. If the same LOH can act singly and as a part of an AH-LOH team, the trials of Table 5 would require 32 AH sorties and 32 LOH sorties. This is based on an average of three trials per sortie for the LOH and two and one-fourth for the AH (i.e., the AH makes three-fourths as many trials per sortie as the LOH makes). The trials of Table 6 would require 16 AH sorties and 16 LOH sorties, based on four trials per LOH sortie and three trials per AH sortie.

Specific numbers of aircraft and crews to support these estimates can best be determined by the operational units supporting the test in view of their expected maintenance capabilities and crew strength.

The numbers of sorties for each day of testing can be determined from the experimental designs in Chapter II. On some days there are eight trials of single fixed-wing aircraft; on other days there are four trials of single aircraft and four trials of four aircraft. Either six or eight trials of helicopters are planned for each day. Unless delays occur due to instrumentation, range availability, gun system reliability, etc., these numbers of trials can be accomplished in two periods of about 2 hours' duration each. All of the trials could be accomplished in 28 days of testing. Considering the delays that may occur, the test is expected to continue over a period of 6 to 8 weeks.

4. Mission Planning

Mission profiles should result from a coordinated effort between technical advisors and operational planners to ensure that the factor levels for each trial are translated into operational instructions. Mission profile cards should be

provided for each aircraft for each mission in order that a planned sequence of attack headings, popup positions, and maneuvers will be performed. Standard tactical maneuvers are required and are to be performed with the minimal variation possible. New tactics may be an outgrowth of this field test; however, the use of individualized maneuvers during the test would degrade the data obtained.

B. ANTIAIRCRAFT GUN SYSTEMS

1. Types of Antiaircraft Guns

The types of antiaircraft guns to be tested in this field test are the twin 23mm antiaircraft gun, ZU-23; the single 57mm antiaircraft gun, S-60; and the twin 35mm antiaircraft tank, 5PFZ-B. Two separate S-60 guns will be required. One of these must be equipped with the basic on-carriage optical-mechanical fire control system, AZP-57; the 1-meter-baselength stereoscopic rangefinder, ZDN; and the commander's observation telescope, TZK. The other S-60 must have the PUAZO 6-60 fire director with integrally mounted optical sights, the SON-9 radar, and the TZK. Provision of the two S-60 guns will enable simultaneous testing of both fire control systems. The 5PFZ-B antiaircraft tank combines twin 35mm Oerlikon guns, a Contraves fire control system, a search radar, and a tracking radar on a Leopard combat tank chassis. This system represents a state-of-the-art self-propelled air defense unit. The particular unit provided for this field test has been in development testing in the Federal Republic of Germany (FRG). Since its configuration may be changed before it becomes available for the test, documentation of the final configuration should be provided by Oerlikon-Contraves or the FRG.[1]

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[1]Details of the ZU-23 and S-60 are available in Antiaircraft Gun Systems--Eurasian Communist Countries, DIA Document ST-CS-07-02-72, Vol. I, SECRET. Details of the 5PFZ-B are available in 35mm AA Weapon System on Leopard Combat Tank Chassis, Type 5PFZ-B, Oerlikon-Contraves Report No. 2980, UNCLASSIFIED.

2. Test Ammunition

Various types of ammunition were considered to provide the gunners a realistic test environment. Lethal ammunition precludes the use of manned aircraft, and without manned aircraft the guns would not be faced with the realistic combat maneuvers of interest. Blank rounds present a problem in the functioning of automatic weapons, and they fail to create a realistic recoil environment. In view of these difficulties, breakup (disintegrating) projectiles were selected. The use of breakup ammunition requires that miss distances and probabilities of hit be computed on the basis of gun pointing angles and ballistics data. This imposes a stringent instrumentation requirement (see Chapter III). Nevertheless, use of breakup ammunition is considered the best approach.

Breakup ammunition has been developed and used in calibers similar to those planned for this test. In particular, the FRG has purchased several million rounds for use in field training and has used over two million rounds successfully. For this series of tests, breakup ammunition is being developed by the U.S. Army at Picatinny Arsenal in the 57mm caliber, is being procured under contract by Frankford Arsenal in the 23mm caliber, and can be purchased from the FRG source in the 35mm caliber.

The ammunition development programs include a provision for safety certification of the breakup ammunition so that it will be acceptable for use on WSMR. Additionally, the certification will include tests to ensure disintegration of all projectiles into fragments or particles harmless to personnel or aircraft beyond 100 meters from the muzzle.

In addition to the breakup ammunition required for the field tests, an estimated 500 rounds per crew per gun should be allocated for crew training prior to the field tests--a total allowance of 2,000 rounds per gun system. Lethal ammunition will

be the only type available for the 23mm and 57mm calibers in time for crew training prior to field testing. Training ammunition for the 5PFZ-B units should be included in the contractor training program at the Oerlikon-Contraves facility.

Prior to the field tests, a pretest trial should be conducted to allow for instrumentation checkout and to ensure that operational coordination is satisfactory. This would include firing breakup ammunition at attacking aircraft for a full-up systems check. One hundred rounds per gun should be adequate for this check and can be taken from the quantities on order cited above.

The quantity of ammunition required for the field tests is as follows:

	Lethal Rounds	Breakup Rounds
23mm	2,000	15,000
35mm	--	10,000
57mm	4,000	10,000

3. Guncrews

a. Crews for the Field Tests

Field testing requires four guncrews per weapon for the duration of the tests. Table 13 identifies the functions to be performed and the numbers of personnel required for each guncrew. Guncrew manning would be: 5PFZ-B, 2; ZU-23, 5; S-60 with the optical-mechanical fire control, 8; and S-60 with the PUAZO fire director, 14--a total of 29 crewmen for one set. Four sets of crews would raise this total to 116 crewmen. Provision of spare crew members can be selective to some degree since less technical positions, such as ammunition handlers, can be filled by quickly trained general duty personnel. Further, certain of the S-60 positions are duplicated through the use of two versions of the basic weapon. In consideration of these

Table 13. GUNCREW REQUIREMENTS BY FUNCTION (SINGLE FIRING UNIT)

Function	Crew Member Performing Function					
				S-60 (Full Fire Control System)		
	5PFZ-B	ZU-23	S-60 (On-Carriage FCS)	Gun	PUAZO Director	SON-9 Radar
Overall Direction	Commander	Crew Chief	Gun Commander	Gun Commander	Fire Director Commander	Radar Commander
Fire Gun(s)	Commander	Gunner	#1 Gunner	#1 Gunner	--	--
Track Tgt--Az	Commander	Gunner	#1 Gunner	#1 Gunner	Az Operator	Az & El Operator
--El	Commander	Gunner	#2 Gunner	#2 Gunner	El Operator	Az & El Operator
Computer Input Rng	Gunner	Asst Gunner	#3 FC Operator	--	Rng Operator	Rng Operator
Tgt Spd, Climb & Dives	Gunner	Asst Gunner	#4 FC Operator	--	--	--
Tgt Ht	--	--	--	--	Ht Operator	--
Ammo Loading	(Automatic Belt)	Ammo Bearer (RT)	#5 Loader	#5 Loader	--	--
		Ammo Bearer (Left)	#6 Ammo Hdlr	#6 Ammo Hdlr	--	--
			#7 Ammo Hdlr	#7 Ammo Hdlr	--	--
No. Crew in Unit	2	5	8	6	5	3
No. Crew in System	3[a]	5	8	--	14[b]	--

[a]Full operational crew includes tank driver; not required for fixed-position firing.

[b]Battery Commander and staff would be an addition for full battery operation. For field test purposes with a single gun representing a normal battery complement (6-8 guns), the additional command and control staff can be optional.

factors, 2 extra crewmen should be provided for the 5PFZ-B; 2 extra gunners for the ZU-23; and 16 extra crewmen for the two S-60 systems as follows: 1 gun commander, 2 No. 1 gunners, 2 No. 2 gunners, 1 No. 3 fire control operator, 1 No. 4 fire control operator, 2 No. 5 loaders, 2 ammunition handlers, 3 fire director operators, and 2 radar operators.

A total of 136 gun crewmen should provide a complement of 4 operating guncrews for each gun system in the test, satisfying gun functional requirements plus minimal spare personnel. Particular Service-connected personnel requirements may alter this number. In the event that a shortage of gunner-qualified candidates exists, the minimum number of crewmen needed would be 110, without ammunition handlers. This number would provide four sets of crews plus spares. However, ammunition handlers or bearers would have to be available from other support personnel. A minimum of one ammunition handler for the ZU-23 and each S-60 system per day would be necessary.

b. Exploitation of the Preliminary Tests

The nature and timing of the preliminary tests (see WSEG Report 191) requires that they be in progress during the initial period of preparation for the field tests. This presents an opportunity for training of instructor crews. Employees of the Vitro Corporation at ADTC, Eglin AFB, Florida, have operated the S-60 system; ballistics range personnel at BRL and AFATL, Eglin AFB, Florida, have operated the ZU-23. Service personnel who will instruct the guncrews should be selected early enough to observe preliminary testing and to derive maximum familiarization from it.

c. Personnel Sources

Three principal sources of candidate guncrew personnel exist currently within the U.S. Army: (1) graduating students

of Air Defense School/Advanced Individual Training (AIT) programs, (2) members of VULCAN air defense units, and (3) personnel with experience on DUSTER or quad-50 equipment. The personnel graduating from the AIT program are familiar with U.S. air defense equipment, but since most of their training in gun air defense is received later in operational units, they are not experienced guncrew members. DUSTER- or quad-50-trained personnel are either serving in National Guard units with the equipment or are being used in new specialties within the regular Army. Thus, the best source of candidate guncrew personnel is in VULCAN units in the field. Two VULCAN air defense artillery batteries, either TOE 44-327H or -437H from a single AD battalion, would provide a suitable number of qualified guncrew candidates.

d. Crew Selection

On the basis of induction center testing designed to identify individuals having automotive equipment aptitudes, above average mechanical aptitude, and good visual acuity, Army basic trainees are selected for AIT at the Air Defense School and subsequent duty with air defense units. During unit on-the-job training, the most capable gunners are selected subjectively for senior gunner duties on the VULCAN system. No psychomotor or specialized guncrew skill testing appears to be in use at this time.

To make use of this selection system, candidates for the guncrews should be VULCAN crewmen.[1] Candidates should also be screened through standard psychomotor testing to match natural aptitudes to functional requirements of the field test guns and related systems components, such as optical trackers and radar equipment. Further screening with stress testing devices

[1]Such crewmen are identified by the MOS (Military Occupational Specialty) code 16R.

similar to the equipment used by N. K. Walker Associates, Inc., would enable the field test staff to assemble the trainees into guncrews having similar characteristics. If the crews are designated Crew 1, Crew 2, Crew 3, and Crew 4 for each gun, then all crews designated Crew 1 should share common characteristics. While present testing and selection techniques are not sufficiently refined to predict crew performance, it is believed possible to combine similar talents in separate crews, thereby ensuring a degree of uniformity in the performance capability of crews with similar designations. If the characteristics used for forming the crews are highly correlated with performance in a guncrew, the field test is likely to reveal the correlation.

e. Crew Training

In view of the unique functional characteristics of the test guns, guncrew training should be conducted with selected crew members on their assigned guns or on identical spare guns. In case the training is performed on the test guns, time must be allotted compatible with the instrumentation effort. Classroom facilities are available at WSMR for instruction in gun function theory, firing procedures, tracking techniques, fire discipline, test plan and procedures, and similar areas. An estimate of 8 to 12 weeks for this training is based on current practices in U.S. air defense units, previous experiences of contractor technician crews, and the FRG training experience.

The availability of the FRG 5PFZ-B antiaircraft tank will be such that training at Oerlikon-Contraves in Europe will be necessary. Swiss contractor representatives have estimated this training at 8 to 12 weeks. Training performed by Oerlikon-Contraves or by the FRG should be in gun and fire control operation only, with tank operation and systems maintenance to be performed by a contractor team. The relatively small number (10) of field test crewmen being trained for this system should make this training approach acceptable.

Text material for training crews for the Soviet weapons can be derived from the DIA documents cited in Section B1 with assistance from the U.S. Army Foreign Science and Technology Center. Training texts for the 5PFZ-B unit will be provided by Oerlikon-Contraves during the training program.

f. Crew Integrity

The design of this field test has placed emphasis on the guncrew as an integral test factor. Because of this and the concentrated training needed to conserve time in the test schedule, strict adherence to crew assignments must be maintained. Further, data from the test will be correlated with known crew characteristics and fatigue conditions. Crew changes or substitutions should be avoided; when they are deemed necessary, they must be a matter of test record.

g. Crew Motivation

Information obtained from personnel and records of previous field tests indicates that serious deterioration of the performance of guncrews could occur. Mediocre or haphazard performance by guncrews could produce an artificially low probability of hit with subsequent serious implications in attrition modeling. In a field test such as this, the guncrews have a motivational handicap--the lack of visible destruction of the aircraft. However, as a consequence of the proposed instrumentation, it should be possible to provide a quick-look score for each gun for each trial. Such information should be made available within 24 hours after each firing test. This procedure will provide additional motivation for the crew through an increased sense of participation, and it should stimulate competition between crews.

Other aids to crew motivation can be derived from identifying the importance of the test to combat planning, emphasizing

the special selection of test crew personnel, and providing unit participation (as opposed to a general levy for unassociated individuals that can be spared from a number of organizations). It should be noted that the use of units to participate as gun-crews was the unanimous recommendation of both human resources research scientists and operational unit commanders. The participation of personnel who will have post-test associations introduces peer pressure on the participants and increases their desire to perform successfully.

h. Crew Fatigue

For the purposes of this field test, the difference in performance between a fresh crew and a tired crew is of interest. Limited historical information indicates that guncrews onboard ship have performed successfully despite prolonged engagements and extreme fatigue. The basis for their performance appears to have been the stimulation of combat and a very real interest in survival. While a field test environment will not provide actual combat stimulation nor result in comparable fatigue, it may be possible to use an extended duty cycle combined with physical activity or loss of sleep to produce fatigue in guncrews.

Since the same guncrews are not scheduled to operate the guns on successive days, it may be possible to use the day and night prior to any day on which particular crews are to function in a fatigued condition to get them fatigued. Within limits set by a subjective judgment of safety, use of physical activity and minimal sleep for 24 hours before the beginning of a day of testing could provide substantial fatigue. Moreover, the degree of fatigue could be approximately repeatable for a particular crew and approximately the same for all crews. This does not suggest that the effect of fatigue will be the same for all crews.

Chapter V

RANGE REQUIREMENTS

Based on the availability of range instrumentation, experienced range personnel, proximity of fixed- and rotary-wing aircraft, and minimum interference with other test activities, it is recommended that the test be conducted at White Sands Missile Range (WSMR).[1] WSMR requirements for test information and documentation are contained in Range Users' Handbook, Universal Documentation System, WSMR, 1 July 1970. The Program Introduction Document--which describes the test program, identifies known support requirements and significant program lead times, forecasts events, and generally spells out program requirements--should be submitted to WSMR as early as possible. It is used as a basis for WSMR support planning, including financial aspects, and for the Statement of Capability, which outlines the capability of WSMR to support the program.

Estimates of time required to conduct major test activities are: guncrew training, 8 to 12 weeks; instrumentation system calibration and dry runs, 2 weeks; field test, 8 weeks; and post-test operations and data reduction, 2 weeks. A suggested schedule is shown in Figure 2. The guncrew training and some of the dry runs need not be conducted at WSMR. It will likely be necessary to conduct training at Fort Bliss to allow use of lethal rounds.

The principal requirements that the test will impose on WSMR are summarized in this chapter.

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[1]The area of Fort Bliss that is adjacent to the C Station area of WSMR is a suitable site. A test in this area could be supported by WSMR.

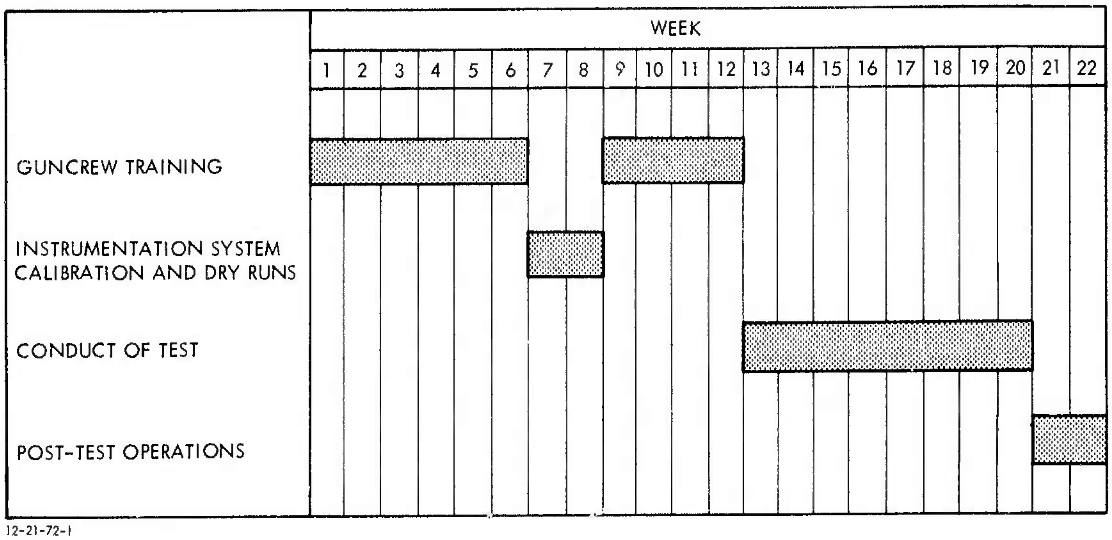

Figure 2. ESTIMATED SCHEDULE OF MAJOR TEST ACTIVITIES AT WSMR

A. PHYSICAL REQUIREMENTS

1. Airspace

Airspace sufficient for realistic operational maneuvers against ground targets by flights of four fixed-wing aircraft and, separately, realistic operational maneuvers by two helicopters is required (see Tables 1, 2, and 3 for maneuvers to be flown). Unrestricted attack directions against the ground target complex are desired. The airspace required for the operational maneuvers has an estimated radius of 15 km about the target area and an altitude of 7 km AGL.

2. Radar Locations

Three AN/FPS-16 radars (R-112, -113, -114) are in fixed installations near C station in the southern portion of WSMR. One mobile FPS-16 equivalent should be emplaced near the three fixed installations. A laser tracker should be positioned about 2 km from the guns, preferably in the direction of the

FPS-16 radars. All FPS-16 and laser tracker locations will be established to first-order survey accuracy (1:25,000). For guncrew safety, the laser tracker should be restricted from pointing directly at the test guns. For further discussion on FPS-16 and laser trackers, see Chapter III.

3. Gun Locations

Two areas--one in WSMR and one in the adjacent part of Fort Bliss--are suitable locations for the guns. The area on WSMR is launch complex (LC) 39, located toward the east end of Nike Avenue. The area on Fort Bliss is southeast of WSMR C station a distance of about 6 km. Unless the use of the Fort Bliss area would make it impractical for WSMR to support the test, this Fort Bliss area is preferable to LC 39 because of proximity to the present FPS-16s and because of terrain that is more suitable to the test.

The gun positions should be carefully selected to facilitate the realistic operational maneuvers to be flown by the target aircraft. Realistic helicopter maneuvers may be difficult to accomplish because the terrain is so gently rolling. At least two locations where a helicopter can hover behind terrain or vegetation mask should be available at ranges of approximately 1, 2, and 3 km from the guns. If feasible, these helicopter popup positions should not be disclosed by dust kicked up by the helicopter as it hovers behind the terrain mask, nor should the helicopter be silhouetted against the sky (viewed from the gun positions) when it pops up.

The four test guns should be emplaced within a 250-meter-radius circle with at least 150 meters between guns. Arrangement of the guns within the circle should be such that the mutual interference in line of sight and line of fire is minimized. For safety considerations, each gun should be restricted from

firing directly at any other gun or at instrumentation vans. Guns should be sited so that they can fire at rotary-wing aircraft at all popup positions and on a variety of straight-line tracks.

On some trials the flight paths of fixed-wing aircraft will be directed toward ground "targets" that are offset from the gun positions (see Chapter II). Colored panels or other easily distinguishable markers should be positioned 1,500 meters from the guns roughly every 60 degrees in azimuth about the guns. These "targets" will assist the crews of fixed-wing aircraft in attaining the prescribed flight paths.

Figures 3 and 4 show possible experimental layouts with guns at LC 39 and with guns southeast of C station at Fort Bliss, respectively. These layouts illustrate the relative locations of the major ground elements of the test.

B. PERSONNEL, FACILITIES, AND EQUIPMENT REQUIREMENTS

1. Administrative and Logistical Support

Billeting, mess facilities, and range transportation are required for approximately 200 test personnel at WSMR. Office and warehouse space, telephone service, and general logistical support will also be obtained from WSMR.

Air Force aircraft and crews should be based and supported at Holloman AFB. U.S. Army helicopters and crews should be based and supported at Fort Bliss.

2. Technical Support

Operation and maintenance of range-furnished instrumentation and data reduction equipment will be provided by WSMR. Maintenance of project-furnished instrumentation and equipment is the responsibility of the project, although limited general maintenance support can be obtained through WSMR.

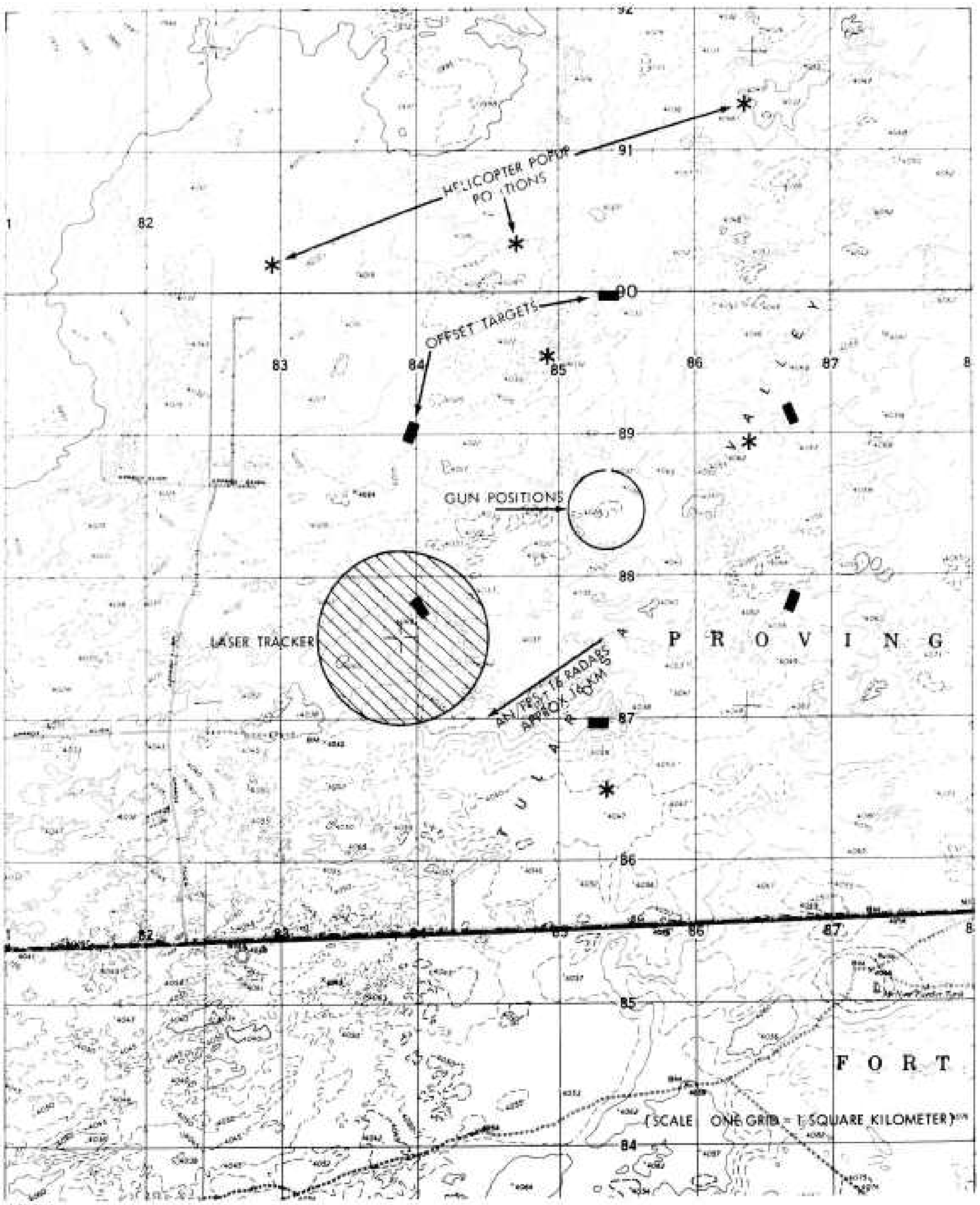

Figure 3. EXPERIMENTAL LAYOUT WITH GUNS NORTH OF NIKE AVENUE, VICINITY LC 39

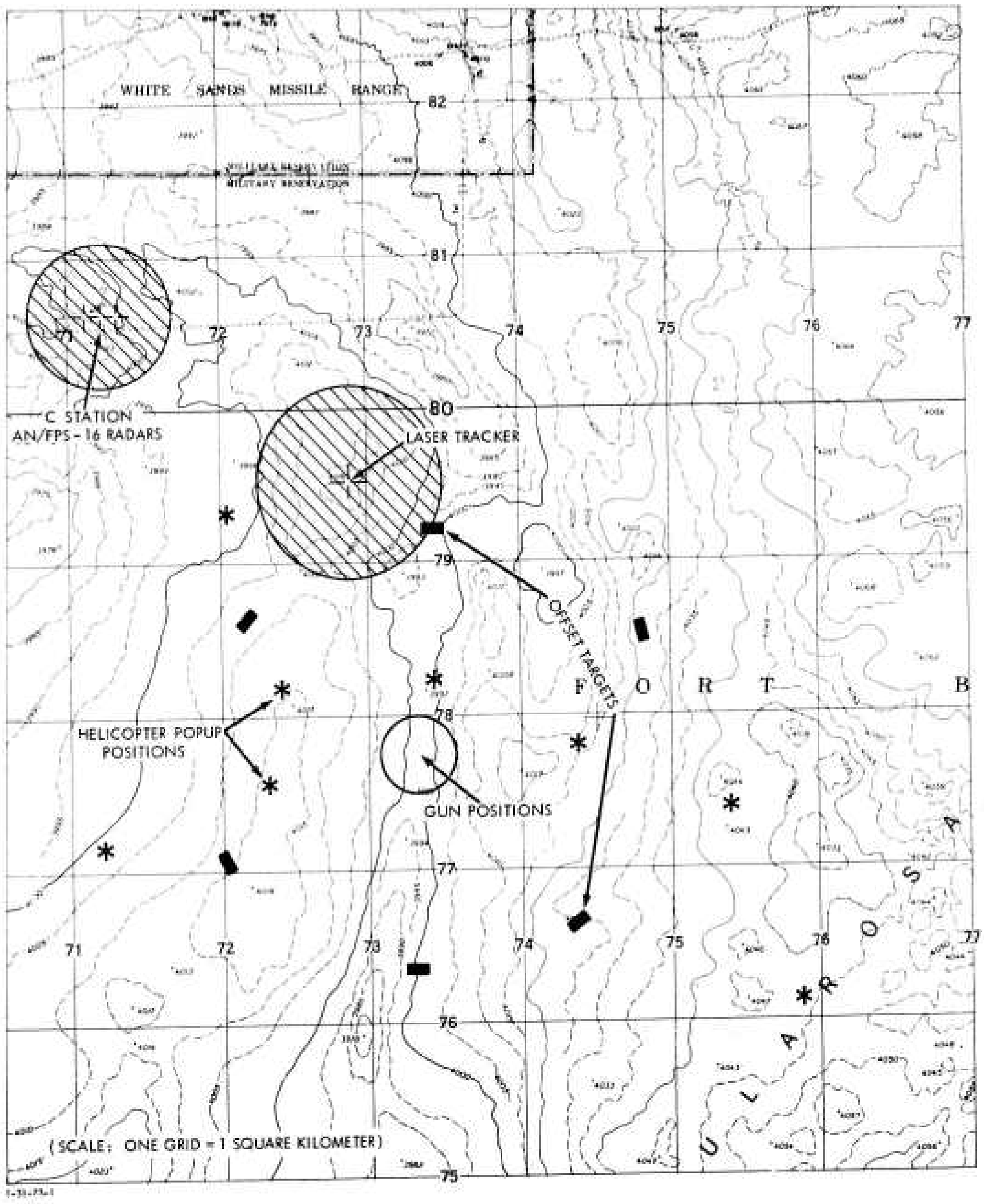

Figure 4. EXPERIMENTAL LAYOUT WITH GUNS SOUTHEAST OF C STATION

C. SAFETY REQUIREMENTS

To introduce the field test program to WSMR, it will be necessary to prepare the Program Introduction Document, the Program Requirements Document, and the Operations Requirements Document. Integral elements of these documents relate to control of operationally hazardous aspects of the test. Specifically, the following are necessary:

- Safety Standing Operating Procedures containing Detailed Operating Instructions for each operation (ref. WSMR Reg. 385-15).
- Certification of Operational Hazards using STEWS-NR-P Form 1, Operational Hazards, supported by safety certifications for breakup ammunition and the gun systems to be used in testing.
- WSMR Radiological Health and Safety Standards (ref. WSMR Reg. 40-8) to establish safe use of a laser tracking system as well as to provide for safe siting of guns relative to radars.
- Mission folders to describe the operational activities of aircraft in support of test operations at WSMR (ref. AFMDC Regulation 55-6). Special provisions and coordination for the use of TAC aircraft at WSMR will be consistent with applicable TAC procedures and the cited AFMDC regulation. Army aviation procedures in effect for helicopters providing support at WSMR should be suitable for this field test.

The information necessary to initiate safety planning for the field test may be obtained from the Range Users' Handbook and the above cited regulations. Additional information and guidance may be obtained through the Range Programs Office, Deputy for National Range Operations, WSMR.

Chapter VI

PRELIMINARY PLAN FOR ANALYSIS AND EVALUATION

The data as originally recorded during the field test will be processed by the Joint Service Test Director in accordance with the data requirements presented in Chapter III. WSEG/IDA will then analyze the data and use them to assess the validity of several mathematical models. The present chapter describes the plan for the WSEG/IDA analyses. The methodology will be further developed before the test is conducted, and changes in the plan will undoubtedly occur.

A. ANALYSIS OF THE TEST DATA

The test data will be analyzed to explain the performance of each gun system tested. The data elements to be measured in the field test (listed in Chapter III) were chosen for the purpose of determining probability of hit and for investigating some of the most important functions of antiaircraft gun systems--determining position and velocity of the aerial target, predicting future positions of that target, and computing the aimpoint.[1] The manner in which these functions are performed differs with gun type; consequently, the data elements measured and the specific computations required to explain the performance of the gun systems also differ with gun type.

All of the guns obtain the direction to the target (azimuth angle Θ and elevation angle Φ) by tracking the target with optical

[1]Other important functions such as projectile lethality and weapon mobility will not be measured in the field test.

devices or radar. Several measures of merit for angular tracking performance will be computed for a prescribed interval before and after the aerial target passes the gun. It is important to exclude the early part of the flight path from this calculation. During this initial period, tracking is very accurate but relatively unimportant. Inclusion of this initial time period would improve the apparent overall accuracy and bear little relation to the probability of hit. The measures of merit include (1) the fraction of time that the angular tracking error is less than some prescribed value (possibly weighted by a function of range) and (2) the root mean squared error (i.e., the square root of the mean of the squares of the errors measured at intervals during the period of interest). Since the tracking errors are serially correlated (autocorrelated with time), the computation of root mean squared error will use sufficiently large intervals between data points so that the correlation is small. Selection of the appropriate interval size may be based on spectral analysis of the angular tracking error.

For the twin 35mm antiaircraft gun (5PFZ-B) and the single 57mm antiaircraft gun (S-60) with the PUAZO fire director, the range r to the target will be obtained by radar. For these guns the errors in range will be analyzed in about the same way as the errors in angular tracking. The other guns (with optical-mechanical fire control) will obtain range by use of a hand-held stereoscopic rangefinder. One crew member will use the rangefinder and call out ranges, while another crew member attempts to adjust the range dial (input to the fire control system) to match the ranges being called out. Errors in such estimated ranges are likely to exhibit a high serial correlation. Spectral analysis will be used to determine the frequency content and correlation coefficients of these time series. The root mean squared error will also be computed.

The 5PFZ-B and S-60 with the PUAZO fire director will be operating in a mode in which target velocity is obtained by differentiating target position data and smoothing to minimize the effects of noise in that data. These systems also perform a coordinate transformation of r, Θ, ϕ, $\dot{r}$, $\dot{\Theta}$, $\dot{\phi}$ to cartesian coordinates x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$. For these systems the smoothed $\dot{x}$, $\dot{y}$, $\dot{z}$ will be measured by the appropriate analog voltages within the fire directors. Errors in the computed velocities (i.e., computed velocities minus the velocities measured by range instrumentation) will be analyzed by the same method used for the errors in angular and range tracking.

The other guns (with optical-mechanical fire control) will use target velocity in terms of the speed, course angle, and climb or dive angle of the aerial target. These three quantities will be estimated by one crew member and inserted by him into a mechanical computer. These computer inputs will be changed intermittently during an encounter. Analysis of these data will include plotting histograms or cumulative frequency curves of (1) the size of the input error just before an adjustment is made and (2) the size of the error just after an adjustment is made. In addition, the correlation between values of (1) and (2) and between sequential values of (2) will be computed.

One of the best measures of the performance of an antiaircraft gun system relative to its theoretical performance is the difference between the observed gun pointing angles and those which would be required to theoretically get a hit. The latter angles are those which would result in a projectile on the mean trajectory hitting the aircraft if the aircraft proceeded on a straight line during the time of flight of the projectile.[1]

[1]For the twin 23mm weapon (ZU-23) and the S-60 weapons, the aircraft is assumed to continue at constant speed; for the 5PFZ-B, the aircraft is assumed to change speed as a function of the rate of change of speed at the time a projectile is fired.

These differences in pointing angles will be computed at intervals for each engagement, and the root mean square of these differences will then be determined.

The mean miss vector will also be computed at intervals for each engagement.[1] If there are N intervals and if DX and DY are the components of the miss vector in a plane perpendicular to the line of sight from the gun, then the following three measures will be computed:

$$A = \left\{ \frac{1}{N} \sum_{i=1}^{N} DX_i^2 \right\}^{\frac{1}{2}} \qquad B = \left\{ \frac{1}{N} \sum_{i=1}^{N} DY_i^2 \right\}^{\frac{1}{2}} \qquad C = \left\{ A^2 + B^2 \right\}^{\frac{1}{2}}$$

Measure C is the root mean square of miss distance. The mean of the mean miss vectors will also be computed.

The probability of hit will be obtained by integrating the projectile dispersion over the projected area of the aircraft or an equivalent projected area. Probability of hit for each engagement will be computed on two bases--for all rounds actually fired and for all rounds that would have been fired if a specified firing rate could have been maintained throughout the engagement. Values computed for rounds actually fired will reflect employment with limited supplies of ammunition; the other values can provide an upper limit on probability of hit for an engagement.

It will be desirable to determine the effect of each factor in the experimental design on probability of hit and the other measures of merit. The design presented in Chapter II is devised so that the effect of each factor (main effect) and each pair of factors (two-factor interactions) can be estimated from the

[1]The mean miss vector is the vector between a projectile on a mean trajectory and the target. It can be defined either at the time of closest approach or at the time when the aircraft and projectile are the same distance from the gun. The latter definition is the more convenient.

data by standard analysis-of-variance procedures. The analysis-of-variance model for the design in Table 4 is

$$y_{ijklmnpq} = \mu + \beta_i^C + \beta_j^F + \beta_k^A + \beta_l^B + \beta_m^D + \beta_n^E + \beta_p^H + \beta_q^S + \beta_{ij}^{CF} + \beta_{ik}^{CA} + \ldots + \beta_{nq}^{ES} + \beta_{pq}^{HS} + e_{ijklmnpq}$$

Here y is the observation of a particular trial. For example, it could be the probability of hit for the trial. The Greek letters denote parameters to be estimated, the superscripts identify the factors related to the parameters, and the subscripts denote the levels of the corresponding factors. The parameters having only one superscript are the main effects, while those having two superscripts are the two-factor interaction. μ is a constant over all trials of the design, and e is a random variation of the observation of a particular trial from the expected value of the observation for that trial. Analysis of variance will be employed to analyze the probability of hit data, the root sum square of mean miss distances, and the root sum square of tracking errors.

Several of the measures described above require the mean trajectory of a projectile. The mean trajectory will be computed with the modified 3-degrees-of-freedom model developed by Ballistics Research Laboratory.[1] This program uses inertial and aerodynamic characteristics of the projectiles and integrates the equations of motion. The effects of winds are included in the computation. This model has been validated and used extensively. The computational methods and ballistics data used in applying this simulation to the main test are to be confirmed

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[1]Robert F. Lieske and Mary L. Reiter, Equations of Motion for A Modified Point Mass Trajectory, BRL Report No. 1314, March 1966.

by the Ballistics Verification Test for the ZU-23 and S-60.[1] Existing data will be used for the 5PFZ-B.

B. VALIDATION OF MODELS

The models that are currently being investigated and compared by WSEG/IDA are P001, FAIRPASS, EVADE II, and SIMFIND. The validation effort will be directed toward some or all of these models, depending on the outcome of the present investigation and comparison.

1. Types of Models

The models are of two basic types--expected value and Monte Carlo--each requiring different treatment in some of the analyses described in this section.[2] The expected value models--P001 and FAIRPASS--operate generally as follows: The true aircraft position and velocity are found deterministically for the time a round is fired by use of input data and an interpolation procedure. The mean theoretical intercept point is computed as the point at which the projectile would hit the aircraft if the aircraft were to proceed at constant speed in the direction in which it is traveling when the round is fired, if the projectile had mean interior and exterior ballistics, and if it were perfectly aimed.

In the real world, the aircraft does not ordinarily proceed in unaccelerated flight, the projectiles vary from their mean performance, and the guns are not perfectly aimed. The models account for the variations in aiming by estimating the errors in the input values to the fire control computer and computing the resulting errors in aimpoint on the assumption that the

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[1]The Ballistics Verification Test is one of three preliminary tests described in WSEG Report 191, op. cit.

[2]EVADE II is a systematic sample model that is somewhat like the expected value models and somewhat like the Monte Carlo model.

fire control computer performs its computations perfectly. All of the models treat these errors as being normally distributed, and all except P001 assume that mean error is always zero.[1] The models then compute a round-to-round dispersion and combine this with the aimpoint dispersion to obtain an overall dispersion for the projectile about the mean theoretical intercept point. This combined dispersion is integrated over some representation of the projected area of the aircraft at its actual position when a projectile (with mean performance) would have arrived at the aircraft. This provides the probability of hit for a particular round. The single-shot probabilities of hit are combined statistically to obtain the probability of hit for the encounter.

The Monte Carlo model--SIMFIND--performs computations that are very similar to those of the expected value models. The essential difference is that in the Monte Carlo approach the distributions of errors in the inputs to the fire control computer are sampled and the aimpoint is computed on the basis of particular realizations of the errors. The aimpoint is determined for each round in this manner, and probability of hit is computed for each projectile by an integration of round-to-round dispersion over some representation of the projected area of the aircraft. After computing the probability of hit for the complete engagement, the entire process is repeated with a different sample of errors. After repeating the procedure numerous times, the average of the values of encounter probability of hit is computed and is used as the estimate of encounter probability of hit.

2. Approach to Validation

As mentioned in Chapter I, *validation* of a model means determination of the differences between data computed with

[1]The models differ from each other both in the values of estimated errors in the inputs to the fire control system and in the transformation of these errors to errors in aimpoint.

the model and comparable data that would result from many actual occurrences of the phenomena being modeled. In the HITVAL program, the models will be validated with respect to data from the field test.

Validity of the models will be assessed with respect to several of the principal functions of gun systems as well as encounter probability of hit. Unless a model agrees with the field test data for tracking, aimpoint determination, etc., one cannot be confident that it will exhibit the correct sensitivities with respect to changes in these functions.

The measures of merit to be employed are similar to those to be used for describing the performance of the gun systems. The principal measure will be the square root of the mean of the squares of differences between the model results and field test results. For example, consider the azimuthal tracking angle. Let Θ_t^s denote the azimuthal angle of the sight measured in the test, and let Θ_m^s denote the same angle in a model. Define $\Delta\Theta_i^s$ to be $\Theta_m^s - \Theta_t^s$ at time i, i = 1,2,...,N. Then the measure is

$$\left\{\frac{1}{N} \sum_{i=1}^{N} (\Delta\Theta_i^s)^2\right\}^{\frac{1}{2}}$$

The period of observation and the interval between the N observations must be determined as described in Section A.

The measure just described is applicable to systems with fire directors whether they are tracking optically or by radar. A slightly different measure is more appropriate for the guns with optical-mechanical fire control systems. For these guns the error in tracking is measured directly in the field test, and the error in tracking is computed in the models. In this case $\Delta\Theta^{es} = \Theta_m^{es} - \Theta_t^{es}$ would replace $\Delta\Theta^s$. Here $(\ )^{es}$ means error of the sight angle. This measure is related to the former one since $\Theta_t^{es} = \Theta_t^s - \Theta_t^{as}$ and similarly for Θ_m^{es}. Here $(\ )^{as}$

means the actual angle of the line of sight. Therefore, $\Delta\Theta^{es} = \Delta\Theta^{s} - (\Theta_m^{as} - \Theta_t^{as})$.

Similar measures have been defined for elevation angle of the sight or radar, for range, and for the components of the miss vector.

The values computed in expected value models (for tracking error, miss vector, etc.) and used in the measures just described are either the expected values of the variables or approximations of the expected values. The models also compute the variance of these variables. This permits a statistical hypothesis test to be performed as follows: Let the null hypothesis be that the field test data for an encounter are a sample from the normal distribution assumed by a model, and let the alternative hypothesis be that the field test data are from any other distribution. Let x be the random variable (e.g., azimuth tracking error), and let m and s be the mean and standard deviation of x as computed by the model. Under the null hypothesis, $y \equiv (x - m)/s$ is $N(0,1)$; that is, y is from a normal distribution with mean 0 and variance 1. Then a test that y is $N(0,1)$ would be performed.

For example, suppose the length of time of interest is divided into N intervals. Let m_i and s_i be the values of m and s for the i^{th} interval, and let x_i be the value of x observed in the field test for this interval. Consider the hypothesis that y_i is a sample from $N(0,1)$ for $i = 1,2,\ldots,N$, where $y_i = (x_i - m_i)/s_i$. A test of this hypothesis is equivalent to a test that x_i is normal with mean m_i and standard deviation s_i for $i = 1,2,\ldots,N$. The tests for normality can involve computation of the first four moments, the chi-square test, or the Kolmogorov-Smirnov test.

Hypothesis testing of the type just described will also be applied to the Monte Carlo model. For this model the values of m and s can in some cases be taken directly from the sampled distributions. In other cases (e.g., aimpoint or miss vector)

m and s will have to be estimated from the sample of values computed by the model.

Some of these hypothesis tests may indicate that the alternative hypothesis should be accepted (i.e., that the field test data are from a distribution other than the model distribution). This result would imply that the model distribution should be modified. It might be possible to find new parameters of the model distribution for which the null hypothesis can be accepted. However, if no such set of parameter values can be found, the functional form of the model must be considered invalid. In this case it will be necessary to find a different functional form for the model. Any extensive model modification is beyond the scope of the present project.

The overall validity of the models will be tested by analysis of variance. For each trial, the models will be used to calculate probabilities of hit that correspond to those described in Section A. If a model is valid, these probabilities of hit should be nearly equal to corresponding values from the field test throughout the experimental design. The following procedure will be used to test model validity on the basis of probability of hit. The procedure will be described for the Monte Carlo model. Then a change of procedure to make it applicable to the expected value models will be mentioned:

- For each trial, the probability of hit values from the field test, PH_t, will be transformed to a random variable that has zero mean and unity standard deviation under the null hypothesis that the field test data are a sample from the distribution represented by the model. The transformed random variable is $(PH_t - PH_m)/SPH_m$, where subscript m refers to the model and SPH means standard deviation in probability of hit.
- Analysis of variance will be performed on the transformed observations. If the model is equally valid throughout the experimental design, the main effects and two-factor interactions should be small

and the hypothesis that they are zero should not be rejected by a statistical test. The standard F-ratio statistic can be used.

The expected value models do not produce an estimate of the standard deviation of probability of hit. However, from results of the Monte Carlo model, it has been observed that the (sample) standard deviation is roughly equal to the (sample) mean of probability of hit. It is reasonable to use $PH_m(SPH_{MC}/PH_{MC})$ as an estimator of the standard deviation for the expected value models in the transformation of observations just described. Here subscript MC refers to the Monte Carlo model.

The differences in the root mean squares of miss distance (measure C in Section A) may prove to be a more useful dependent variable than probability of hit for this analysis-of-variance procedure. The procedure outlined above would be applicable to either variable.

3. Development of Methods for Validation

It is likely that some of the planned validation procedures will not prove to be useful because of the nature of the observed phenomena. To verify and improve the procedures, data will be generated with the Monte Carlo model; these data will be used as simulated field test data in the validation procedures.

Thirty-two aircraft flight paths from the design given in Tables 1 and 4 have been generated on a computer by AFATL, Eglin AFB, Florida. The Monte Carlo model will simulate a single trial for each of these flight paths. The results will then be labeled "test data." These test data will be compared to corresponding results generated by the models by using the various validation techniques. It is hoped that such a dry run will permit an improvement of validation procedures.